THE INTERNATIONAL SPACE STATION: ADDRESSING OPERATIONAL CHALLENGES

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

July 10, 2015

Serial No. 114–30

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE

97–570PDF WASHINGTON : 2016

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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THE INTERNATIONAL SPACE STATION: ADDRESSING OPERATIONAL CHALLENGES

FRIDAY, JULY 10, 2015

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 9:03 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Brian Babin [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
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Subcommittee on Space

The International Space Station: Addressing Operational Challenges

Friday, July 10, 2015
9:00 a.m. to 11:00 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. Bill Gerstenmaier, *Associate Administrator, Human Exploration and Operations Mission Directorate, NASA*

Mr. John Elbon, *Vice President and General Manager, Space Exploration, The Boeing Company*

The Honorable Paul K. Martin, *Inspector General, NASA*

Ms. Shelby Oakley, *Acting Director, Acquisition and Sourcing Management, Government Accountability Office*

Dr. James A. Pawelczyk, *Associate Professor of Physiology and Kinesiology, The Pennsylvania State University*

U.S. House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Space

The International Space Station: Addressing Operational Challenges

HEARING CHARTER

Friday, July 10, 2015
9:00 a.m.
2318 Rayburn House Office Building

Purpose

At 9:00 a.m. on Friday, July 10, 2015, the Subcommittee on Space will hold a hearing titled *The International Space Station: Addressing Operational Challenges*. The purpose of this hearing is to examine the current status of the International Space Station (ISS). The Subcommittee will evaluate the National Aeronautics and Space Administration's (NASA) plans for dealing with operational and maintenance challenges, the status of the ISS partnership, how NASA is utilizing the ISS to enable future deep space exploration, and the Administration's request to extend ISS operations to 2024.

Witnesses

- **Mr. Bill Gerstenmaier,** Associate Administrator, Human Exploration and Operations Mission Directorate, NASA;
- **Mr. John Elbon,** Vice President and General Manager, Space Exploration, The Boeing Company;
- **The Honorable Paul K. Martin,** Inspector General, NASA;
- **Ms. Shelby Oakley,** Acting Director, Acquisition and Sourcing Management, Government Accountability Office.
- **Dr. James A. Pawelczyk**, Associate Professor of Physiology and Kinesiology, The Pennsylvania State University

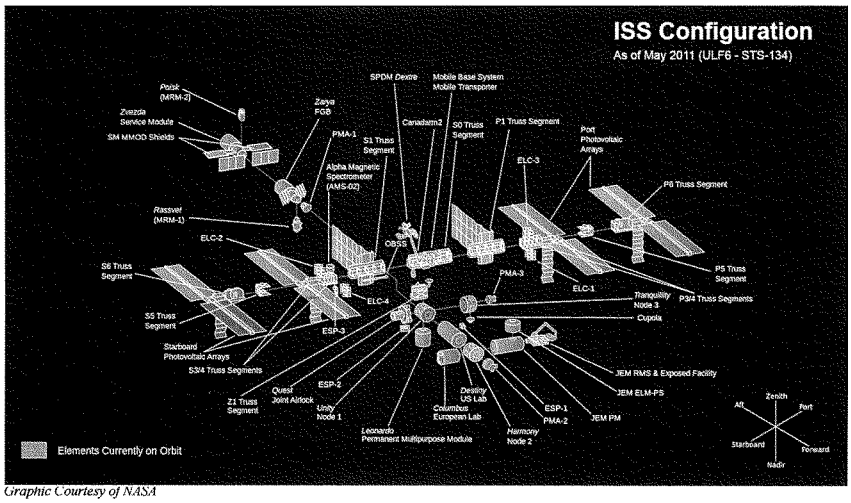
Background

The ISS is one of the most complex and expensive man-made structures ever built.[1] The ISS is a joint project among five participating space agencies—NASA, Roscosmos (Russian Space Agency), the European Space Agency (ESA), Japanese Aerospace Exploration Agency (JAXA), and Canadian Space Agency (CSA). The ISS orbits approximately 250 miles above the Earth's surface once every 90 minutes at five miles per second. Weighing in at nearly one million pounds, it is the length of a football field (including end zones) and has the equivalent working

[1] The NASA Inspector General estimates that the United States has invested almost $75 billion which includes "$43.7 billion for construction and program costs through 2013, plus $30.7 billion for 37 supporting Space Shuttle flights, the last of which took place in July 2011." Extending the Operational Life of the International Space Station Until 2024 (IG-14-031). Retrieved at: https://oig.nasa.gov/audits/reports/FY14/IG-14-031.pdf.

and living space of a six bedroom home. The pressurized living space is approximately equal to a Boeing 747. The solar arrays used to power the Station would cover nearly an acre and eight miles of electrical wiring powers various sections of the facility. Out of the global space launch market, launches to the ISS accounts for approximately 15 percent of the total. For 2013-2014, this was 25 out of 168 total launches worldwide.[2]

Among other benefits, the ISS provides a proving ground for NASA's human exploration technologies and other NASA mission directorates and various federal agencies as well as a microgravity laboratory for private companies. The ISS generally operates with a rotating crew of six astronauts from the U.S. and international partner space agencies, though at times this drops to three crewmembers as is the case at present.



Graphic Courtesy of NASA

The United States currently launches cargo resupply missions to the ISS through the Commercial Resupply Services (CRS) contract. The Russian *Progress* and Japanese *HTV* also provide cargo resupply to the ISS.

The two U.S. providers under this contract, Orbital ATK and Space Exploration Technologies Corporation (SpaceX), provide cargo delivery services on a firm fixed-price contract. The two providers carry supplies for the astronauts as well as science and research equipment to the ISS in conjunction with international partners.

[2] Launch history is based on data compiled by the FAA's Office of Commercial Space Transportation (AST) Annual Commercial Space Transportation Compendium found at:
https://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAA_Annual_Compendium_2014.pdf

NASA currently lacks a domestic capability to ferry astronauts to and from the ISS. American astronauts (and international partners) are reliant on the Russian Soyuz which launches from the Baikonur Cosmodrome in Kazakhstan. NASA's existing contract for Russian Soyuz runs through 2017 and costs roughly $75 million a seat.[3] NASA recently announced that it is negotiating a new contract with Russia for services from 2017 to 2018.[4] Last fall, NASA signed contracts with Space Exploration Technologies (SpaceX) and the Boeing Company to develop and provide transportation to and from the ISS through the Commercial Crew Program (CCP).

Once the Commercial Crew program begins ferrying astronauts to the ISS, NASA may be able to add a seventh crew member. This has the potential of increasing research and utilization time on the station equivalent to approximately 35 hours a week.[5] In fiscal year 2014 (FY14), the Station hosted 368 experiments (a 28 percent increase from FY13). These included 64 in biology and biotechnology, 91 in Earth and space science, 50 educational activities, 36 in human research, 43 in physical science, and 84 in technology.[6] The utilization of the unique microgravity environment on the ISS is augmented by the Center for Advancement of Science in Space (CASIS). This non-profit organization was chosen in 2011 in accordance with the NASA Authorization Act of 2010.[7]

Budget

	Actual	Enacted	Request	FY15 vs	Notional			
Budget Authority ($ in millions)	2014	2015	2016	FY16	2017	2018	2019	2020
Space Operations	3,774.0	3,827.8	4,003.7	175.9	4,191.2	4,504.9	4,670.8	4,864.3
International Space Station	2,964.1	-	3,105.6	-	3,273.9	3,641.0	3,826.0	4,038.3
Space and Flight Support (SFS)	809.9	-	898.1	-	917.3	863.8	844.8	826.1

The Space Operations Account funds activities for the International Space Station, cargo delivery, and space flight and support. These activities fall under NASA's Human Exploration and Operations Mission Directorate. The President's Space Operations budget request for FY16 is $4.003 billion, which represents an increase of $175.9 million (4.6 percent). Of this, operations, crew and cargo transportation, and research aboard the ISS accounts for $3.105 billion. For these same activities, the House Appropriations bill includes $3.075 billion[8] (3.2 percent increase over FY15)[9] and the Senate Appropriations bill includes $3.051 billion[10] (2.5 percent increase over FY15).[11]

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[3] *Ibid.* 1, p. 21.
[4] NASA Sole-source Procurement Announcement of Crew Transportation and Rescue Services from Roscosmos https://prod.nais.nasa.gov/cgibin/eps/synopsis.cgi?acqid=163919
[5] ISS utilization projections are courtesy of NASA delivered via staff briefings in February and March of 2015 in support of the President's Budget Request.
[6] President's Budget Request for Fiscal Year 2016 for the National Aeronautics and Space Administration, Congressional Justification. P. SO-14. Retrieved at http://www.nasa.gov/sites/default/files/files/FY2016_Budget_Book_508_TAGGED.pdf
[7] Section 504 of the National Aeronautics and Space Administration Authorization Act of 2010. Retrieved at https://www.congress.gov/111/plaws/publ267/PLAW-111publ267.pdf
[8] Title 3, H.R. 2578, Commerce, Justice, Science and related agencies Appropriations Act of 2016. Retrieved at https://www.congress.gov/bill/114th-congress/house-bill/2578/text/rh?q={%22search%22:[%22%22hr2578%22%22]}
[9] Based on estimates from NASA's FY15 spending plan submitted to Congress
[10] Title 3, H.R. 2578, S. Rep. 114-66. Retrieved at https://www.congress.gov/114/crpt/srpt66/CRPT-114srpt66.pdf
[11] *Ibid.* 9.

The prime contractor for operations and maintenance of the ISS is the Boeing Company. This accounts for $1.106 billion of the overall Space Operations account in the FY16 budget request. Operations and maintenance includes managing resources, logistics, systems, and operational procedures. Additionally, the operations and maintenance project manages resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The project is also responsible for providing anomaly resolution and failure investigations as needed.

Commercial Cargo

The Commercial Spaceflight program at NASA began in 2006 by funding multiple companies to develop systems for transporting cargo to the ISS with an eye towards eventually having multiple carriers compete for the resupply contract. This was accomplished through the Commercial Orbital Transportation Services (COTS) and Cargo Resupply Services (CRS) programs. At this point, both of the companies involved, Orbital ATK and SpaceX, have successfully delivered cargo to the ISS. While the SpaceX contract includes a down-mass capability (returns cargo to Earth), Orbital ATK's *Cygnus* spacecraft (like the Russian Progress, European Space Agency's ATV or the Japanese Space Agency's HTV) has no down-mass capability. In 2008, NASA signed two CRS contracts. The SpaceX contract is valued at $1.6 billion for 12 missions and Orbital ATK contract is valued at $1.9 billion for eight missions.[12] Regardless of anomalies or accidents, the cost associated with these launches is set and paid out in increments as various milestones are met through the manufacturing process. The final payment is not made unless the payload docks with the ISS and delivers the cargo. In some cases, substantial portions of the contract may be paid out prior to delivery of the cargo.[13]

On October 28, 2014, Orbital ATK attempted to launch its *Cygnus* cargo ship to the ISS carrying 5,000lbs. of supplies and science experiments. Approximately 15 seconds after launch the Antares rocket suffered a catastrophic failure and the rocket as well as the *Cygnus* were lost. The investigation into the exact cause is ongoing. In the meantime, Orbital ATK procured the services of United Launch Alliance (ULA) to launch its next *Cygnus* payload to the ISS. This flight is required under the company's CRS contract and it is tentatively scheduled for launch in October. As the CRS contract is firm-fixed price, the use of a different rocket and altered launch conditions will not financially impact the government.

On April 28, 2015, the Russian *Progress* resupply vehicle, M-27M launched from Kazakhstan carrying 5,196lbs of cargo to the ISS. After achieving orbit, the *Progress* vehicle suffered several anomalies that resulted in the loss of the vehicle. The Progress-60 launched on July 3, 2015 carrying 6,100lbs of cargo and docked with the ISS on July 5, 2015.

On June 10, 2015, while performing various software testing procedures there was an inadvertent firing of thrusters used to control the orbit of the ISS. The Russian and American engineering teams are the process of identifying the root cause, but as of yet have not released any public findings.

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[12] NASA Awards Space Station Commercial Resupply Services Contracts. Retrieved at http://www.nasa.gov/home/hqnews/2008/dec/HQ_C08-069_ISS_Resupply.html

[13] Commercial Cargo: NASA Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts. NASA Office of Inspector General released on June 13, 2013. Retrieved at https://oig.nasa.gov/audits/reports/FY13/IG-13-016.pdf

On June 28, 2015, SpaceX attempted to launch its seventh cargo resupply mission to the ISS. At approximately 139 seconds after lift-off, the rocket suffered a catastrophic failure that resulted in the loss of the vehicle. The unmanned *Dragon* capsule was carrying approximately 5,000 pounds of pressurized cargo, including research experiments, food, crew provisions and exercise equipment. Additionally, the vehicle was carrying a replacement spacesuit for EVA activity, this suit was necessary after water started seeping into the helmet of one of the spacesuits in December 2013. The cause of the SpaceX launch failure is still under investigation. As with the Orbital ATK launch failure, the contractor will be responsible for the investigation with participation and oversight from NASA, Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB) in accordance with FAA regulations for licensed commercial launches.

The extent to which these three failures over the course of eight months will affect the ISS program is unclear. NASA announced that the astronauts aboard the Station are in no immediate danger and that they have enough food, water, and oxygen to last until September. The next resupply mission of a Japanese HTV is scheduled to be launched in August.[14]

Commercial Crew

NASA awarded fixed-price contracts to Boeing and SpaceX in September 2014 for the Commercial Crew program. The total potential values of these contracts are $2.6 billion for SpaceX and $4.2 billion for Boeing for a total of $6.8 billion over the life of the contracts. These two companies will proceed through the final design, development, testing, evaluation and human rating certifications under a fixed-price contract.

The President's budget request for FY16 includes $1.24 billion for the Commercial Crew Program. This would be an increase of 54 percent over the appropriated funding for FY2015 ($805 million). In testimony before this Committee earlier this year, a NASA official stated that

> *"[i]f NASA does not receive the full requested funding for CCtCap in FY 2016 and beyond, NASA will have to adjust (delay) milestones for both partners proportionally and extend sole reliance on Russia for crew access to the ISS. The partners may request contract cost adjustments and the certification dates will be delayed."*

Federal Acquisition Regulations (FAR)[15] and the commercial crew contracts[16] do allow NASA to adapt their acquisition strategy for one or two contractors to accommodate varying appropriation levels. Despite the $6.8 billion projected value of the contracts, NASA has never completed an independent cost estimate of the Commercial Crew Development Program or the

[14] Statement by NASA Administrator Charles F. Bolden, Jr. June 29, 2015. Retrieved at https://www.nasa.gov/press-release/nasa-administrator-statement-on-the-loss-of-spacex-crs-7

[15] Federal Acquisition Regulations 52.249-2, Termination for Convenience of the Government (Fixed-Price). Retrieved at http://www.ecfr.gov/cgi-bin/text-idx?SID=d3e3b99553af16abc0188213eee065c3&mc=true&node=se48.2.52_1249_62&rgn=div8

[16] Clause B.4 Post Certification Missions, Clause H.4 NFS 1852.232-77 Limitation of Funds (fixed-price contract), Clause H.8 Post Certification Mission Task Ordering Procedures (Applicable to CLIN 002), Commercial Crew Transportation Capability (CCtCAP) Contract with Boeing (NNK14MA75C), Commercial Crew Transportation Capability (CCtCAP) Contract with SpaceX (NNK14MA74C). Retrieved at http://www.nasa.gov/centers/kennedy/about/foia/reading_room.html#.VZKzV_lVhBc

program estimates that the companies provided for their funding requirements;[17] however, the contracts are fixed-price, meaning they are capped at the agreed upon levels. This does not guarantee that the contractors will not need to be bailed-out in the event that they are unable to complete the contractual work.

The NASA Authorization Act of 2010 authorized $312 million, $500 million, and $500 million for the Commercial Crew Program for fiscal years 2011, 2012 and 2013 respectively. NASA has consistently requested more funding for Commercial Crew than the program has been authorized or previously appropriated.[18] Three years ago, the NASA Administrator testified before the Committee that the FY13 request would put NASA "on track" for a commercial crew capability by 2017.[19] The actual appropriation for FY13 was $305 million less than the request. Two years ago, the Administrator testified to the Committee that NASA was still on track for a 2017 launch date, but full funding of the FY14 request was "essential" to enabling Commercial Crew access to the International Space Station by 2017.[20] The actual appropriation for FY14 was $125 million less than the request. The FY16 NASA budget justification states that 2017 is still the target date for a Commercial Crew capability. The Committee-passed NASA Authorization Act for FY16 and FY17 included full funding for the Commercial Crew program. Funding history for the program is included below.

Funding History *$ in millions*	**Program Phase**					
Partner	CCDev1	CCDev2	CCiCap	CPC1	CCtCap	Total
Paragon	1.40	-	-	-	-	1.40
United Launch Alliance	6.70	-	-	-	-	6.70
Blue Origin	3.70	22.00	-	-	-	25.70
Sierra Nevada	20.00	105.60	227.50	10.00	-	363.10
SpaceX	-	75.00	460.00	9.60	2,600.00*	3,144.60
Boeing	18.00	112.90	480.00	9.90	4,200.00*	4,820.80
Total Funding	49.80	315.50	1,167.50	29.50	6,800.00	8,362.30

Source - http://www.nasa.gov/sites/default/files/files/CCtCapFactSheet.pdf

*Represents total potential value of the contract.

[17] NASA contracted with Booz|Allen|Hamilton to complete an independent cost assessment of the program which was released on March 1, 2013 and can be found here http://www.nasa.gov/pdf/741617main_CCP-ICA-DRD-2e-Public-Releaseable-Final-Report-3-5-13-508.pdf. However, as noted by the NASA Inspector General, "the assessment found that the estimates were optimistic, and that the Program was likely to experience cost growth. In addition, Booz Allen noted that without costs projected over the life of the Program, NASA officials will not be able to independently evaluate each partner's progress."

[18] FY2011 request: $500 million. FY2011 actual: $307 million. FY2012 request: $850 million. FY2012 actual: $392 million. FY2013 request: $830 million. FY2013 actual: $525 million. FY2014 request: $821 million. FY2014 actual: $696 million.

[19] Charles F. Bolden, Jr., Administrator, National Aeronautics and Space Administration, statement before the House Committee on Science, Space, and Technology, March 7, 2012.

[20] Charles F. Bolden, Jr., Administrator, National Aeronautics and Space Administration, statement before the House Committee on Science, Technology, and Space, Subcommittee on Space, April 24, 2013.

***Orion* as a Backup**

In addition to the use of commercial crew contractors, NASA is required under federal law to ensure that the *Orion* crew vehicle has the capability to dock to the ISS in an emergency.[21] The law,[22] which was passed by Congress and signed by the President, was very specific in describing this as a "minimum capability requirement"[23] for the capsule. It is important to note that the law does not require *Orion* to be launched by the Space Launch System (SLS). While *Orion* may not be an efficient vehicle to conduct ISS transportation missions, the ability to conduct a mission to the ISS would provide redundancy and additional options for access. At present, NASA is not building the *Orion* with the capability to service the ISS. In an interview with *Space News* in June 2014, Administrator Bolden expressed his view of the legal requirement for *Orion* to serve as a backup capability:

> *"It's a bad, bad day when you have to send Orion to the international space station because it means either we've lost each of the [commercial] vehicles that was designed to do that through some accident, or they failed or something. So we don't want to have to rely on Orion to do that.*
>
> *"We made a commitment to industry we would not compete with them.*
>
> *"If we had said, 'We're going to keep Orion as a backup,' there were serious doubts as to whether industry would have made the investment at all in a commercial crew vehicle because their assumption was, 'OK, if NASA is going to build a vehicle to go to low Earth orbit, what is NASA going to want to use?' Naturally, they're going to want to use their own vehicle.*
>
> *"So Orion, while it probably can — or will — be capable of going to the international space station, is not designed to do that, is not intended to do that."*[24]

Given the subsequent launch failures with the Orbital ATK and SpaceX cargo vehicles as well as the loss of the Russian *Progress* vehicle over the course of the past year, the potential loss of commercial crew capabilities seem to have a higher likelihood of possibly occurring.

It is unclear how NASA would handle such a situation given the current state of the development efforts of *Orion*. The Administration has consistently requested less than has been previously appropriated for the program. In the FY13, FY14, and FY15 budget requests, the Administration asked for reductions of $175.1 million, $87 million, and $144.2 million from previous year funding.[25] It is difficult to assess the ability of NASA to press the *Orion* into service for emergency crew transfer capabilities while simultaneously requesting reductions to the budget for the program.

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[21] Title 42, §18323(b)(3), United States Code
[22] National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267). Retrieved at http://www.gpo.gov/fdsys/pkg/PLAW-111publ267/pdf/PLAW-111publ267.pdf
[23] Title 42, §18323(b), United States Code
[24] Klotz, Irene, "Orion No Backup for Commercial Crew, Says Bolden," SpaceNews, June 18, 2014. Accessed at http://www.spacenews.com/article/civil-space/40957orion-no-backup-for-commercial-crew-says-bolden
[25] President's Budget Requests for Fiscal Year 2013, Fiscal Year 2014, and Fiscal Year 2015.

ISS Utilization

Since inception of the ISS, utilization of the facility has been an ongoing concern of Congress. There are several factors that limit the amount of research that can be conducted on the ISS at any given time; the most limiting of these is crew time to perform the experiments. Additionally, NASA's Inspector General reported last year that only about 41 percent of crew time was used on utilization and research.[26] NASA claims that, once the Commercial Crew contractors are providing consistent service, the addition of a seventh crew member could nearly double research time.

The NASA Authorization Act of 2010 required NASA to procure the services of a non-profit entity to run the National Laboratory portion of the ISS. NASA awarded this cooperative agreement to the Center for the Advancement of Science in Space (CASIS). The GAO recently reviewed the progress CASIS has made towards satisfying the requirements of their agreement. Generally speaking, the organization is making good progress, but there are still questions about the efficacy of the National Lab. According to GAO it is difficult to assess the progress made by CASIS in fulfilling its requirements under the cooperative agreement because NASA has not established a formal process for doing so:

> *"Using the established metrics, NASA is required by the cooperative agreement to perform an annual program review of CASIS's performance. This review is informal and not documented as ISS program officials provide the results to CASIS orally. This approach is inconsistent with federal internal control standards, which call for information to be recorded and communicated to those who need it to manage programs, including monitoring performance and supporting future decision making. Although NASA officials reported that they were generally satisfied with CASIS's performance, CASIS officials said a formal summary of the results would make the information more actionable."*[27]

In addition to CASIS activities, NASA is required to maximize use of the ISS. The NASA Authorization Act of 2010 requires NASA to "sustain the capability for long-duration presence in low-Earth orbit, initially through continuation of the ISS and full utilization of the United States segment of the ISS as a National Laboratory, and through assisting and enabling an expanded commercial presence in, and access to, low-Earth orbit, as elements of a low-Earth orbit infrastructure."[28] Additionally, NASA is required to utilize the ISS as a "testbed" for technologies developed for future human exploration in deep space.[29] Finally, NASA must "maximize the productivity and use of the ISS with respect to scientific and technological research and development, advancement of space exploration, and international collaboration."[30]

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[26] *Ibid.* 1, p. 7.
[27] Government Accountability Office report #GAO-15-397, "Measurable Performance Targets and Documentation Needed to Better Assess Management of National Laboratory." Retrieved at http://www.gao.gov/assets/670/669851.pdf
[28] Section 202, National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267). Retrieved at http://www.gpo.gov/fdsys/pkg/PLAW-111publ267/pdf/PLAW-111publ267.pdf
[29] Section 308(c), National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267). Retrieved at http://www.gpo.gov/fdsys/pkg/PLAW-111publ267/pdf/PLAW-111publ267.pdf
[30] Section 502(a) National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267). Retrieved at http://www.gpo.gov/fdsys/pkg/PLAW-111publ267/pdf/PLAW-111publ267.pdf

For fiscal year 2016, NASA requested $394 million for the purpose of microgravity research aboard the ISS. This represents approximately 9.8 percent of the total budget for the Space Operations account or about 35 percent of what it costs for the operations and maintenance of the program. The ISS currently supports activities for the Science Mission Directorate space and Earth science payloads, Space Technology Mission Directorate, Human Research Program (HRP), and Advanced Exploration Systems (AES). In addition to the ISS research program, NASA utilizes the ISS as a testbed for technology development in the Space Technology Mission Directorate and the Science Mission Directorate. The NASA Authorization Act of 2015 passed by the House by unanimous consent explicitly authorized the use of the ISS for this purpose.[31]

The ongoing experiments, future experiments, and ISS utilization efforts can be reviewed in detail at http://www.nasa.gov/mission_pages/station/main/index.html. The most notable of these experiments include:[32]

- Study on the effects of long-term spaceflight on astronaut Scott Kelly and cosmonaut Mikhail Kornienko. Both astronauts will spend almost a full year in space.
- Leveraging microgravity environment for protein crystal grown and disease models to aid study of human diseases such as Huntington's, cystic fibrosis, ALS, and others.
- Creation of a searchable publicly accessible database on biological flight data for use by academia, industry, and other federal agencies to retrieve and analyze science conducted on organisms flown in space.
- Multi-generational, long duration fruit fly laboratory research to aid in human research. As fruit flies share 77% of human disease genes, this provides for a unique study scenario.
- Development of Cold Atom Laboratory with research teams that includes three Nobel Laureates.
- Demonstrate 3D in-space printing as a first step in the "machine shop" capability for long-duration deep space human exploration.
- Conduct Bigelow Expandable Activity Module (BEAM) demonstration. This activity supports the AES program in understanding inflatable habitat use in deep space.
- Continuing operation of the Alpha Magnetic Spectrometer (AMS), a state of the art particle physics detector with a primary mission to find evidence of dark matter. The initial positron science results have been referenced in 279 astrophysics/physics publications.

While NASA's use of the ISS has improved in recent years, there are still areas of concern with regards to utilization. There is a lack of a unified federal government strategy for utilization of the facility. The NASA Authorization Act of 2015 requires the Administration to develop a federal government-wide utilization plan.[33] Additionally, the recent launch accidents resulted in the loss of research equipment and technology assets that may limit the utilization of the Station for at least the immediate future.

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[31] Section 213 and Section 503, H.R. 810, National Aeronautics and Space Administration Authorization Act of 2015, retrieved at http://www.gpo.gov/fdsys/pkg/BILLS-114hr810rfs/pdf/BILLS-114hr810rfs.pdf

[32] Examples of ISS experiments and utilization are courtesy of NASA via staff briefings delivered in February and March of 2015 in support of the President's Budget Request.

[33] Section 211(g), H.R. 810, National Aeronautics and Space Administration Authorization Act of 2015, retrieved at http://www.gpo.gov/fdsys/pkg/BILLS-114hr810rfs/pdf/BILLS-114hr810rfs.pdf

ISS Extension to 2024

Last year, the Administration proposed extending the life of the ISS from 2020 to 2024, but has not provided its plan to get commitments from the international partner space agencies or budget requirements for the extension.[34] NASA is currently authorized to operate the ISS until 2020 under current law.[35] The extension of the program requires legislative action. As the Administration works to get the international partner nations to agree to extend the ISS, the House-passed NASA Authorization Act of 2015 includes a requirement that NASA provide an extension criteria report to Congress. This report would provide Congress with a baseline and notional plan to evaluate the merits of extending the program.[36]

The NASA Inspector General (IG) released a report on ISS extension in September 2014. The IG found several areas of concern with regards to extension. First, that NASA had not identified major structural obstacles to extension but that several risk areas required mitigation. According to the report,

> *"First, the ISS faces a risk of insufficient power generation due in part to faster than expected degradation of its solar arrays. Second, although most replacement parts have proven more reliable than expected, sudden failures of key hardware have occurred requiring unplanned space walks to repair or replace hardware. Third, although NASA has a robust cargo transportation system, it has a limited capacity to transport large replacement parts – such as solar arrays and radiators – to the Station."* [37]

The IG also found that cost projections for extension appeared overly optimistic. According to NASA officials, the budget for the ISS will remain between $3 billion and $4 billion annually through 2024. In the judgment of the IG, "this estimate is based on overly optimistic assumptions and the cost to NASA will likely be higher."[38] NASA does not have a public estimate on the costs associated with extension. However, a recent Congressional Budget Office (CBO) cost estimate on the ISS extension provision in S. 1297, The U.S. Commercial Space Launch Competitiveness Act,[39] estimates that, should appropriations be allocated under the extension, it would cost the government approximately $14.3 billion over the next ten years to extend the ISS operating life to 2024.[40]

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[34] Statement by NASA Administrator Charles F. Bolden, Jr. January 8, 2014 http://blogs.nasa.gov/bolden/2014/01/08/obama-administration-extends-international-space-station-until-at-least-2024/
[35] Title 51, §70907, United States Code.
[36] Section 211(f) National Aeronautics and Space Administration Authorization Act of 2015, retrieved at http://www.gpo.gov/fdsys/pkg/BILLS-114hr810rfs/pdf/BILLS-114hr810rfs.pdf
[37] *Ibid.* 1, p. ii.
[38] *Ibid.* 1, p. iii.
[39] Section 13, S. 1297, U.S. Commercial Space Launch Competitiveness Act. Retrieved at http://www.gpo.gov/fdsys/pkg/BILLS-114s1297is/pdf/BILLS-114s1297is.pdf
[40] Congressional Budget Office Cost Estimate of S. 1297. Retrieved at http://www.cbo.gov/sites/default/files/114th-congress-2015-2016/costestimate/s1297.pdf

Key Questions

1. What are the costs associated with extension of the ISS and how are those costs measured against the benefits of extension?
2. How can Congress assess whether the ISS program is meeting its goals and objectives and how can those metrics inform the costs and benefits of extension?
3. If Congress does not extend ISS operations beyond 2020, what impact would that have on the U.S. Space Program?
4. What can NASA expect to gain by extending the ISS beyond 2024?
5. Is there an optimal date for extension beyond 2020?
6. Are there any technical concerns that would limit extension beyond a certain date?
7. How does NASA plan to mitigate the extension concerns expressed by the Inspector General?
8. What are the impacts on utilization of the ISS associated with the three cargo flight failures and how will those impacts be mitigated by NASA and the international partners?
9. Will ISS crew be limited as a result of the cargo failures, and if so, how will that impact utilization?
10. What steps have been taken to mitigated risks associated with reliance on private contractors for crew and cargo transportation?
11. Has NASA taken the appropriate steps to ensure that the *Orion* can serve as a backup to the commercial crew contractors in an emergency situation?

Chairman BABIN. The Subommittee on Space will come to order. Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time. Good morning. Welcome to today's hearing titled The International Space Station: Addressing Operational Challenges. In front of you are packets containing the written testimony, biographies, and Truth in Testimony disclosures for today's witnesses. I recognize myself for five minutes for an opening statement.

Good morning. I'd like to welcome everyone to our hearing today, and I want to thank our witnesses for taking time to appear before our Committee. Since 2013, the ISS program has experienced a number of challenges. As a can-do nation, America has always been committed to identifying challenges, addressing them, and advancing to reach out and reach our goal and destiny. We have that same commitment with the ISS. During this time, astronauts have experienced water leaks in their suits three times, with one incident occurring during a spacewalk. On April the 26th, 2013, an unmanned Russian Progress cargo vehicle damaged a laser radar reflector when docking with the ISS. On January the 14th, 2015, a false alarm of an ammonia leak caused the crew to retreat into the Russian segment. On October 28th, 2014, an Orbital Sciences unmanned cargo launch failed just after launch. On April the 28th, 2015, a separate Russian Progress cargo vehicle failed to reach the ISS. On June the 7th, 2015, a planned re-boost of the ISS using a docked Progress vehicle failed but eventually was successful after troubleshooting. On June the 10th, 2015, a visiting Soyuz vehicle unexpectedly fired its engines without being commanded. Most recently, on June the 28th, 2015, a SpaceX unmanned cargo launch failed as well.

All of these incidents highlight the challenges of operating in space, and they remind us that NASA's contractors, engineers, and astronauts must be ever vigilant. These events have challenged ISS operations, but the fact that the program was able to effectively respond to these set-backs is a testament to NASA, the ISS partners, and the contractors. We do not know the root causes of some of the accidents yet, but once we have more information, we will be better suited to review those individual events. In the meantime, this hearing allows us to evaluate the operational status of the ISS, review efforts to utilize the unique asset, and assess the prospects for future operations.

The ISS is one of the most complex and expensive man-made objects ever built. The American taxpayers currently invest approximately $3 billion dollars per year in this laboratory. We must ensure that every dollar is spent effectively and efficiently. The ISS offers a unique microgravity environment for scientists and engineers to utilize. NASA recently released its Benefits to Humanity publication this week detailing the many benefits that ISS provides back to our lives here on Earth. From advances in our understanding of human health and performance to our use of new materials to the utilization of robotics and satellites, the benefits we receive from ISS are many and diverse and remarkable.

In addition to the benefits here on Earth the ISS offers the conditions necessary to prepare and develop critical technologies for deep space and long-duration human spaceflight missions. Succes-

sive NASA authorizations direct the administration to utilize the ISS for this purpose. The Human Research Program and Advanced Exploration Systems Program at NASA are on the cutting edge of developing the systems we need to send humans ever deeper into the Solar System than ever before. Right now, Captain Scott Kelly is on day 104 of his year-long mission to study the effects of long-duration human spaceflight.

In addition to the utilization efforts of NASA's research programs, the NASA Authorization Act of 2005 designated part of the ISS as a National Lab and the NASA Authorization Act of 2010 directed the administration to sign a cooperative agreement with a non-profit to manage it. NASA selected the Center for the Advancement of Science in Space, or CASIS, to lead this effort. The Government Accountability Office noted in a recent report that CASIS had made great strides in fulfilling the mandate under the law but that more work needed to be done to ensure that measurable progress was being made in a quantifiable manner. I hope to hear from NASA today that the agency is making progress towards answering this recommendation from GAO.

As we keep an eye on the present operation and utilization of the ISS, we must also look to the future. Last year the administration announced support for the extension of the ISS program from 2020 to 2024. At present, federal law limits the life of the ISS to 2020. Absent action from Congress to extend it, the administration would be required to begin closeout of the program.

There are many questions about the request for this extension. The bipartisan, House-passed NASA Authorization Act of 2015 requires the administration to provide a report to Congress on efforts by the administration to utilize the ISS and how to quantify benefits back to the nation for the required investment for this extension. It also requires the Administration to develop a government-wide utilization plan for the ISS to ensure that every minute the facility is in orbit we are doing what we can to get the most out of it. These reports are critical for Congress to understand the issues that inform whether to extend the ISS.

This Committee has a responsibility to ensure that the American taxpayers are getting all that they can from every dollar they send to the federal government. I believe this investment is worthwhile and that the benefits far outweigh the cost. Support for the ISS and its operations and utilization is not a partisan issue. It is an American issue, and I look forward to working with my friends on the other side of the aisle and our partners in the space industry to understand how we can all meet the operational challenges facing the ISS program.

[The prepared statement of Chairman Babin follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
CHAIRMAN BRIAN BABIN

Good morning. I would like to welcome everyone to our hearing today and I want to thank our witnesses for taking time to appear before the Committee.

Since 2013, the ISS program has experienced a number of challenges. During this time, astronauts have experienced water leaks in their suits three times, with one instance occurring during a spacewalk. On April 26, 2013, an unmanned Russian Progress cargo vehicle damaged a laser radar reflector when docking with the ISS. On January 14, 2015, a false alarm of an ammonia leak caused the crew to retreat

into the Russian segment. On October 28, 2014, an Orbital Science's unmanned cargo launch failed just after launch. On April 28, 2015, a separate Russian Progress cargo vehicle failed to reach the ISS. On June 7, 2015 a planned re-boost of the ISS using a docked Progress vehicle failed but eventually was successful after troubleshooting. On June 10, 2015, a visiting Soyuz vehicle unexpectedly fired its engines without being commanded. Most recently, on June 28, 2015, a SpaceX unmanned cargo launch failed as well.

All of these incidents highlight the challenges of operating in space, and remind us that NASA's contractors, engineers, and astronauts must be ever vigilant. These events have challenged ISS operations, but the fact that the program was able to effectively respond to these set-backs is a testament to NASA, the ISS partners, and the contractors. We do not know the root causes of some of the accidents yet, but once we have more information, we will be better suited to review those individual events. In the meantime, this hearing allows us to evaluate the operational status of the ISS, review efforts to utilize the unique asset, and assess the prospects for future operations.

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In addition to the benefits back on Earth the ISS offers the conditions necessary to prepare and develop critical technologies for deep space and long-duration human spaceflight missions. Successive NASA Authorizations direct the Administration to utilize the ISS for this purpose. The Human Research Program and Advanced Exploration Systems program at NASA are on the cutting edge of developing the systems we need to send humans deeper into the Solar System than ever before. Right now, Captain Mark Kelly is on day 104 of his year-long mission to study the effects of long duration human spaceflight

In addition to the utilization efforts of NASA's research programs, the NASA Authorization Act of 2005 designated part of the ISS as a National Lab and the NASA Authorization Act of 2010 directed the Administration to sign a cooperative agreement with a non-profit to manage it. NASA selected the Center for the Advancement of Science in Space, or CASIS, to lead this effort. The Government Accountability Office noted in a recent report that CASIS has made great strides in fulfilling the mandate under the law but that more work needed to be done to ensure that measurable progress was being made in a quantifiable manner. I hope to hear from NASA today that the agency is making progress towards answering this recommendation from GAO.

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There are many questions about the request for this extension. The bipartisan, House-passed NASA Authorization of 2015 requires the Administration to provide a report to Congress on efforts by the Administration to utilize the ISS and how to quantify benefits back to the nation for the required investment for extension. It also requires the Administration to develop a government-wide utilization plan for the ISS to ensure that every minute the facility is in orbit we are doing what we can to get the most out of it. These reports are critical for Congress to understand the issues that inform whether to extend the ISS.

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Chairman BABIN. I now recognize the Ranking Member, the gentlelady from Maryland for an opening statement.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and good morning. Welcome to our distinguished panel of witnesses. I appreciate holding this hearing now, The International Space Station: Addressing Operational Challenges, and as I listened to the Chairman, I'm reminded that the challenges that NASA faces and the agency faces in operating the International Space Station, I would be more concerned if we weren't able to overcome some of those challenges, and I think it's a credit to the crew and the partners that that is true.

About a year ago, I and the members of our Committee sat in this room, looked on the screen there, and had the opportunity to communicate with our NASA crew that was aboard the International Space Station, including NASA astronaut Rick Wiseman who's from Maryland. I would note that I promised him crab cakes, and unfortunately one of those accidents that the Chairman referred to destroyed my crab cake delivery. But Rick Wiseman visited with me in my office just a couple of weeks ago and we made okay on that.

What happens when you connect real-time with our astronauts who are living, working, and carrying out research in this amazing laboratory that's orbiting 250 miles above us every 90 minutes is really quite an inspiration.

Thanks to NASA, the crews aboard the ISS, and so many school children have also had the opportunity to ask questions and learn about human spaceflight through similar downlink events that we experienced here in this room. Yet, in the thrill of seeing and hearing those who inhabit our on-orbit laboratory, we can sometimes forget just how difficult, demanding, and risky it is to maintain and operate the International Space Station, because sometimes we think it's just ordinary, and it turns out that it's rather extraordinary. Orbital debris, malfunctions to key systems both internal and external to the ISS, and human health hazards pose significant risks to the ISS facility and its crew. The unfortunate loss of the SpaceX–7 cargo resupply mission less than two weeks ago, along with the earlier losses of the Russian Progress and Orbital ATK cargo missions over the past eight months, are again stark reminders of the risks and challenges that NASA and its partners have to face.

The successful management of these risks for more than 15 years is a testament to NASA and its industry and to international partners.

I am confident that SpaceX, Orbital ATK, in collaboration with the FAA and NASA, will identify and resolve the problems that led to the launch failures and will resume cargo resupply to the ISS as soon as it's safe to do so. And in fact, the ISS actually has been resupplied through its partners.

Mr. Chairman, we don't have any time to spare. The ISS is a temporary facility. It's currently authorized for operations as you've described through 2020, and given that the operations cost about $3 billion in taxpayer dollars every year, a cost that is actually projected to increase, coupled with the challenges involved in sustaining operations, we really need to ensure that our vision for the ISS is clear and our goals and objectives for using this unique facility are aligned with that vision.

I'm pleased that the number of ISS users has actually grown. We've had concerns about that raised here in this Committee. In addition to NASA researchers and NASA-supported academic researchers, the ISS National Laboratory management entity, CASIS, has drawn new commercial users including pharmaceutical companies to the ISS.

However, while the range of ISS uses is expanding, the resources to support those activities are not. Funding for the ISS research represents a mere 12 percent of the overall ISS budget. In addition, constraints on cargo transportation to the International Space Station, as well as available power and precious crew time, limit what research can be accomplished at the Station.

And in that regard, I know that many of us want to understand the implications of cargo resupply interruptions on planned ISS research, crew operations, and the sustainability of the Station.

In addition, Mr. Chairman, there's critical work to be done on the ISS in the areas of human health research and technology development that needs to be carried out if we are going to make progress toward the long-term goal of sending humans to Mars.

In January 2014 the Obama Administration proposed to extend ISS operations until at least the year 2024. The Administration has three rationales for the extension: to complete ISS research that supports long-duration human missions beyond low-Earth orbit; to garner societal benefits from ISS research, some of which we see here; and to give NASA and private partners more time to transition to commercial cargo and crew, allowing NASA to focus on human exploration of deep space.

Today's hearing provides us the opportunity to examine those rationales in the context of the cost and risks that NASA and its international partners will face in sustaining the ISS for that length of time.

So Mr. Chairman, we have a lot to discuss this morning, and I want to thank our witnesses again for being here and with that I yield back.

[The prepared statement of Ms. Edwards follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON SPACE
RANKING MEMBER DONNA F. EDWARDS

Good morning, and welcome to our distinguished panel of witnesses. Thank you, Mr. Chairman, for holding this hearing on "The International Space Station: Addressing Operational Challenges."

About a year ago, I and the members of our Committee sat in this room and had the opportunity to communicate with our NASA crew aboard the ISS, including NASA astronaut Reid Wiseman from Maryland. Connecting real-time with our astronauts who are living, working, and carrying out research in a laboratory orbiting 250 miles above us every 90 minutes is an inspiration.

And thanks to NASA and the crews aboard the ISS, many U.S. school children have the same opportunity to ask questions and learn about human spaceflight through similar downlink events. Yet, in the thrill of seeing and hearing from those who inhabit our on-orbit laboratory, we can sometimes forget just how difficult, demanding, and risky it is to maintain and operate the ISS.

Orbital debris, malfunctions to key systems both internal and external to the ISS, and human health hazards pose significant risks to the ISS facility and its crew. The unfortunate loss of the SpaceX-7 cargo resupply mission less than two weeks ago, along with the earlier losses of the Russian Progress and Orbital ATK cargo missions over the past 8 months, are stark reminders of the risks and challenges that NASA and its partners continue to face.

The successful management of these risks for more than fifteen years is a testament to NASA and its industry and international partners.

I am confident that SpaceX and Orbital ATK, in collaboration with the FAA and NASA, will identify and resolve the problems that led to the launch failures and will resume cargo resupply to the ISS as soon as it is safe to do so.

Because, Mr. Chairman, we don't have time to spare.

The ISS is a temporary facility that is currently authorized for operations through 2020. Given that ISS operations cost about $3 billion taxpayer dollars per year—a cost that is projected to increase, I might add—coupled with the challenges involved in sustaining operations, we need to ensure that our vision for the ISS is clear and our goals and objectives for using this unique facility are aligned with that vision.

Mr. Chairman, I'm pleased that the number of ISS users has grown. In addition to NASA researchers and NASA-supported academic researchers, the ISS National Laboratory management entity, CASIS, has drawn new commercial users including pharmaceutical companies to the ISS.

However, while the range of ISS uses is expanding, the resources to support those activities are not. Funding for ISS research represents a mere 12 percent of the overall ISS budget. In addition, constraints on cargo transportation to the ISS, as well as available power and precious crew time, limit what research can be accomplished on the Station.

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- To complete ISS research that supports long-duration human missions beyond low-Earth orbit;
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Today's hearing provides us the opportunity to examine those rationales in the context of the cost and risks that NASA and its international partners will face in sustaining the ISS for that length of time.

Well, Mr. Chairman, we have a lot to discuss this morning. I want to thank our witnesses again for being here and with that I yield back.

Chairman BABIN. Thank you, Ms. Edwards. I now recognize the Ranking Member of the Full Committee for a statement, the gentlelady from Texas.

Ms. JOHNSON OF TEXAS. Thank you very much, Mr. Chairman, for holding this hearing on the International Space Station. This really is an important topic, and I look forward to the testimony of our panel of witnesses and I welcome them.

It is no secret that I have been a long supporter of the ISS. It plays a unique role in furthering research, advancing human spaceflight, and inspiring our young people. Moreover, in addition to being an incredible engineering achievement, it provides a very visible demonstration of the benefits that can be derived from peaceful international cooperation in space.

Failures of commercial cargo transportation missions to the ISS remind us that spaceflight is not easy. Failures will occur, and unfortunately these failures will have impacts on the program. We need to better understand those impacts, as well as the plans for dealing with them going forward. And we need to know whether there are any lessons learned that need to be applied to the far more challenging Commercial Crew Transportation Program.

I've said before that the ISS is a perishable commodity. We need to be clear on what NASA needs to accomplish with this unique laboratory while it is still operational. While the Administration has proposed to extend ISS operations until 2024, maintaining the ISS involves risk and a significant opportunity cost. We need to ensure that the ISS is being used in a way that maximizes its productivity and value to the nation.

In addition, if we are to ensure that the needed ISS research and technology activities are carried out, it is clear that we are going to need to make the necessary investments. Stagnant ISS research budgets do not communicate the message that we are serious about supporting the important research and technology efforts that can only be accomplished on the ISS. That is a problem that Congress could and should fix.

Well, Mr. Chairman, we have a lot of issues to discuss today. I welcome our witnesses and look forward to a productive hearing. I thank you, and I yield back.

[The prepared statement of Ms. Johnson of Texas follows:]

PREPARED STATEMENT OF FULL COMMITTEE
RANKING MEMBER EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman, for holding this hearing on the International Space Station. This is an important topic, and I look forward to the testimony of our panel of witnesses.

It is no secret that I have long been a supporter of the ISS. It plays a unique role in furthering research, advancing human spaceflight, and inspiring our young people. Moreover, in addition to being an incredible engineering achievement, it provides a very visible demonstration of the benefits that can be derived from peaceful international cooperation in space.

Failures of commercial cargo transportation missions to the ISS remind us that spaceflight is not easy. Failures will occur, and unfortunately those failures will have impacts on the ISS program. We need to better understand those impacts, as well as the plans for dealing with them going forward. And we need to know whether there are any "lessons learned" that need to be applied to the far more challenging commercial crew transportation program.

I have said before that the ISS is a perishable commodity. We need to be clear on what NASA needs to accomplish with this unique laboratory while it is still operational. While the Administration has proposed to extend ISS operations until 2024, maintaining the ISS involves risks and a significant opportunity cost. We need to ensure that the ISS is being used in a way that maximizes its productivity and value to the nation.

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Well, Mr. Chairman, we have a lot of issues to discuss today. I welcome our witnesses and look forward to a productive hearing.

Thank you, and I yield back.

Chairman BABIN. Thank you, Ms. Johnson. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time I would like to introduce our witnesses. Bill Gerstenmaier is the Associate Administrator of the Human Exploration and Operations Mission Directorate at NASA. Our second witness today is John Elbon, Vice President and General Manager of Space Exploration for The Boeing Company. Testifying third is the Honorable Paul Martin who has served as NASA's Inspector

General since 2009. Our third witness is Shelby Oakley, Acting Director of Acquisition and Sourcing Management for Government Accountability Office, GAO. Today's final witness is Dr. James Pawelczyk, an Associate Professor of Physiology and Kinesiology at the Pennsylvania State University and a retired astronaut.

In order to allow time for discussion, please limit your testimony to five minutes. Your entire written statement will be made part of the record.

I now recognize Mr. Gerstenmaier for five minutes to present his testimony.

TESTIMONY OF MR. BILL GERSTENMAIER,
ASSOCIATE ADMINISTRATOR,
HUMAN EXPLORATION AND OPERATIONS
MISSION DIRECTORATE, NASA

Mr. GERSTENMAIER. Thank you, Mr. Chairman, and thank you for the opportunity to testify on behalf of myself and the men and women that work on the International Space Station. This is one of the most talented and dedicated international teams in the world. The ISS is an amazing research facility. Today on the ISS during this expedition, there are 329 research investigations in progress. These span topics from human research into how the human body performs in microgravity, basic biology, and biotechnology, physical science, Earth and space science, technology development, and education. There's never been this scope of research performed on a continuous basis in space.

We are also in the midst of a one-year crew expedition. This mission will give us detailed information into the human adaptation to the space environment with mission durations approximately equal to the Mars transit time. We will also get a unique chance through the twins study to see how the human genome changes when exposed to microgravity. We have kept a continual crew presence on the ISS for almost 15 years. Eighty-three countries from around the world have used the ISS for research. Further, private companies through the National Laboratory and the Center for the Advancement of Science and Space have used the ISS.

This week in Boston there was an ISS users conference. This is an exciting time as many new researchers are beginning to see the advantages of space-based research to augment their terrestrial investigations. The growth of non-NASA research is exciting and shows that there's a generic interest in using the unique properties of space to investigate basic research opportunities typically only done on the Earth.

Space provides a unique window into any physical process that is affected by gravity. Further, the human body reacts in space with many conditions that mimic conditions facing the elderly: bone loss, muscle wasting, immune system degradation, and balance problems. Using animal models, unique insight, and potential new treatments for the elderly can be developed based on Space Station research.

As the Chairman stated earlier, operating under frontier of space is not easy. In the past nine months, three independent cargo vehicles were lost on the way to the ISS. This graphically shows the difficulty of living and operating in space. The lost vehicles have

different designs, different heritages, different manufacturing, different build processes, and utilize different ascent trajectories. The failure of these three systems shows the difficulty of launching and operating in space.

We often think that ISS is only 250 miles away and that the journey is easy. This is not true. We are essentially operating these systems at the edge of our engineering capability. We also often think that if only we provide more insight and oversight, we can lower the risk of cargo delivery. Unfortunately, the demands required to escape Earth's gravity expose us to the same level of risk no matter how much insight we add. But the insight can give us insight and help us understand the designs to make sure that we can end up with better designs.

The right level of insight can reduce and find design errors. However, too much insight can distract the teams from working on and improving design. It's amazing that even after these three failures, the basic ISS operations were not impacted. This is attributed to the teams that manage and operate the ISS. They learned and are implementing the hard lessons from the Columbia tragedy where the ISS had to operate without the shuttle for several years. The consumables management processes and logistics resupply techniques learned are proving their worth. However, these failures are not without consequences. Several of the agency performance goals associated with research and cargo flights will not be met. The ISS program is reducing consumables margins on ISS to favor research. This will not be enough to recover the research impacts. The delay in the Soyuz crew flight, which was required to allow the teams to understand the Progress failure, required the ISS to operate with three crew for approximately three weeks longer than planned and will impact research crew hours. The impact of the loss also had real implications to students and researchers who lost cargo on the Orbital ATK–Cygnus flight only to lose the replacement and return-to-flight hardware again on the SpaceX flight. They suffered a double loss. The loss of the international docking adapter can be accommodated schedule-wise without impacting the crew program but will result in a dollar loss to ISS.

ISS is a phenomenal resource for the nation. The research being done on ISS can be done no place else. ISS can serve as an innovation accelerator for private entrepreneurs, help NASA prepare for journeys beyond low-Earth orbit, and benefits directly people on the Earth. Congressional support for ISS operations through at least 2024 would be a positive sign to the international partners and future users of ISS. Operating on the frontier is not easy, and we need to not get complacent and think ISS operations are routine or easy. They are not. The ISS team has done a great job of managing in a technically demanding environment. The ISS team will continue to look for ways to improve. The ISS teams need to be given flexibility to manage, and others need to understand the benefits of dissimilar redundancy and how it can be used to provide robustness. The benefits of ISS will take longer to be realized than most can envision, but the benefits of ISS will exceed the expectations of all involved.

I would also like to thank the Committee for their support to human spaceflight, especially the authorization activity associated

with Commercial Crew, SLS, Orion, and ISS. I look forward to your questions. Thank you.

[The prepared statement of Mr. Gerstenmaier follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
July 10, 2015

Statement of
William H. Gerstenmaier
Associate Administrator for Human Exploration and Operations
National Aeronautics and Space Administration

before the

Subcommittee on Space
Committee on Science, Space and Technology
U. S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the status of the International Space Station (ISS) Program, as well as our efforts to conduct microgravity research and promote U.S. economic activity in low-Earth orbit (LEO), and expand human spaceflight beyond LEO. The ISS represents an unparalleled capability in human spaceflight that is increasing our knowledge of basic physics and biology. This knowledge is benefiting our lives here on Earth and enhancing the competitiveness of private industry here in the United States. The research and technology demonstrations onboard the ISS are providing the basis for extending human presence beyond the bounds of LEO and taking our next steps into the proving ground of cis-lunar space. With the Administration's proposed extension of the ISS until at least 2024, NASA has the opportunity to more fully utilize research, and commercial and international partnerships to ensure that the U.S. continues to be the world leader in human spaceflight and to enable U.S. industry to realize the commercial benefits of research and development in the microgravity environment of space.

The ISS is vital to NASA's mission to extend human presence into the solar system. In order to prepare for human expeditions into deep space, we must first use the unique environment of ISS to conduct the research and technology demonstrations necessary to keep our crews safe and productive on long-duration spaceflights. The ISS – which has been home to a continuous human presence on orbit for almost 15 years – is NASA's only long-duration flight analog for future human deep-space missions, and it provides an invaluable laboratory for research with direct application to the exploration requirements that address human risks associated with deep-space missions. It is the only space-based multinational research and technology test bed available to identify and quantify risks to human health and performance, identify and validate potential risk mitigation techniques, and develop countermeasures for future human exploration. As NASA learns more about the changes to the human body from spaceflight and develops countermeasures to support long-duration missions, this same research is providing unique insight into problems facing our aging terrestrial population. Through the National Laboratory and the Center for the Advancement of Science in Space (CASIS), U.S. companies are taking advantage of new research opportunities that may provide a competitive edge. Across a range of disciplines and applications, ISS research ultimately benefits people on Earth.

Cargo and Crew Transportation

In order to realize the full potential of the ISS' capabilities, the platform is serviced by a fleet of operational vehicles, including two U.S. cargo resupply vehicles: Space Exploration Technologies'

(SpaceX) Dragon and Orbital ATK's Cygnus. These two providers have flown a combined total of eight cargo missions to the ISS under the Commercial Resupply Services (CRS) contracts, which were awarded on December 23, 2008. The cargo flights have demonstrated the viability of the Government use of commercially provided services – rather than owning and operating the spacecraft and launch vehicles – for the delivery of experiments, supplies, and spares to the Station, enabling NASA to focus its development efforts on deep-space vehicles to take our astronauts beyond LEO. Further, both companies have demonstrated their resourcefulness in dealing with challenges. NASA anticipates awarding one or more CRS-2 contracts later this year.

The overall cargo strategy of having multiple providers has served NASA well, and the importance of having multiple providers is critical for assured cargo access to the ISS, as has been demonstrated by recent losses of Orbital ATK Cygnus, Russian Progress, and SpaceX Dragon cargo flights to ISS. NASA was able to continue ISS operations and research by relying on SpaceX after the Cygnus cargo vehicle anomaly last fall. Orbital is expected to recover and return to flight before the end of 2015. Orbital ATK acquired a launch on an Atlas V vehicle while its Antares launcher is outfitted with a new engine. This strategy allows Orbital ATK to use its Cygnus vehicle and resume cargo delivery capability later this year. The ability of Orbital ATK to quickly integrate Cygnus with an Atlas V is a direct result of their experience in integrating their satellites onto different launch vehicles. The basic CRS-1 contract premise of obtaining cargo services enabled Orbital ATK to creatively acquire a new launch vehicle. This demonstrates the effectiveness of our current contract strategy. Late last month, the SpaceX-7 cargo mission experienced an anomaly during launch. SpaceX has demonstrated extraordinary capabilities in its first six cargo resupply missions to the Station, and we know they can replicate that success. We will work with and support SpaceX to assess what happened, understand the specifics of the failure and correct it to move forward. These events are reminders that spaceflight is difficult, but we learn from each success and each setback, and our commercial cargo program was designed to accommodate the loss of cargo vehicles. With the delivery last week of supplies aboard a Russian Progress vehicle, and with the prospect of a Japanese H-II Transfer Vehicle (HTV) flight in August, we do not anticipate any need to delay the upcoming Soyuz 43S launch later this month, which will return us to six-crew operations and research.

In the area of crew transportation, while NASA continues to develop Commercial Crew capability to provide crew transportation and rescue services to the ISS, the Russian Soyuz spacecraft currently provides these services. The ISS routinely hosts six crewmembers on long-duration missions with the support of two Soyuz spacecraft. The limit in crew size is driven by the Soyuz three-crew-carrying capability. There are currently four Soyuz missions per year to accomplish ISS crew rotations.

NASA's plans for research through 2017 are based having six crew on ISS, including the Human Research Program objectives we need to accomplish during this period to keep on track to reduce or retire risks for deep-space exploration. It should be noted, however, that Station has – from time to time – hosted only three crew during brief transition periods. Before the loss of the SpaceX-7 cargo flight, the current period of three-crew operations had resulted in the deferral of a docking adapter installation, as well as the deferral of some Node 1 preparation tasks. In addition, a rodent experiment was dropped from the SpaceX-7 cargo flight, and some fluid shift experiments were moved to the next Expedition. At this point, NASA anticipates that the current period of having three crew aboard will not last longer than a few weeks, after which, we will staff back up to six crew and resume the normal rate of research activities. Beyond 2017 when U.S. crew providers come on line, our plans count on having an ISS crew complement of seven. Even after losing the docking adapter on SpaceX-7, NASA will have time to add docking capability to ISS to support the first U.S. commercial crew flights.

In 2014, NASA contracted with two U.S. providers for crew transportation and rescue services for ISS. The Commercial Crew Transportation Capability (CCtCap) contracts will complete the development of

domestic systems to provide safe, reliable, cost-effective access to and from ISS. SpaceX's Crew Dragon and Boeing's CST-100 spacecraft will begin ferrying our crews to Station from U.S. soil by the end of 2017, contingent upon receiving the full amount requested in the FY 2016 Budget Request, enhancing the robustness of our transportation system and ending our sole reliance on Russia for the provision of these services. U.S. commercial crew capabilities will enable the Station crew to be expanded from six to seven astronauts and cosmonauts, resulting in a doubling of on-orbit research time to almost 80 hours per week. This is because the seventh crew member will be able to focus his or her time almost exclusively on conducting experiments, rather than on Station operations and maintenance.

I want to thank this Committee for authorizing full funding in FY 2016 for our Commercial Crew Program. It is vitally important that NASA receive this funding level to keep the development of these systems on track for flights in 2017. If the Agency is funded with a Continuing Resolution for the first quarter of FY 2016, NASA will need to address how it will fund our partners' development activities at the current contractual schedule. The CCtCap contractors are only required to work on milestones to the extent that NASA has obligated funding for those milestones. If funding is not available in FY 2016 for the initial FY 2017 milestones, the contractors will have to stop work or work at risk until additional funding can be obligated, existing CCtCap contracts will need to be renegotiated, most likely resulting in schedule delays and increased contract cost, and NASA will need to continue to rely solely on Russian Soyuz capability to meet America's requirements for crew transportation services. NASA has no plans to downselect the number of partners in response to lower-than-requested funding levels. As experience has shown with cargo, NASA's plan to establish a redundant crew transportation capability is critically important for robust, safe ISS operations. This redundancy is even more critical during the development phase. We appreciate the Committee's support for our plan to end sole reliance on Russia for crew transportation through contracts with two U.S. providers.

With over 350 American companies across 36 states working toward this goal, there are significant economic benefits to returning these launches to American soil. At the same time, every dollar we send overseas rather than investing at home represents an investment we could be making in ourselves rather than in the Russian economy.

There are also longer term fiscal considerations to consider. NASA projects that the average seat price will be $58 million per seat for Commercial Crew. The currently contracted seat price for Soyuz for 2017 is approximately $76 million per seat.

Sustainability of ISS and Extension to 2024

The ISS continues to be a very healthy system operating well within prudent technical margins, and consistently demonstrating outstanding steady-state performance that meets or exceeds prior engineering estimates. While systems were originally specified to be both reliable and maintainable, the operational experience NASA and its Partners are gaining is providing invaluable information on reliability and maintainability standards for future application to spacecraft design and mission planning. This enables systems needed for long-duration spaceflight to be tested in preparation for missions far from Earth for which reliability and maintainability are absolutely required. Just as short-duration Space Shuttle flights prepared us for long duration Station flights, ISS is preparing us for missions that will not have the option of immediate crew return in the event of an anomaly.

In January 2014, the Administration announced its intent to extend ISS operations until at least 2024. The research we will conduct on ISS through 2024 will be essential to the safe and effective conduct of human exploration beyond LEO. This extension is also critical to commercial sector planning for the use of the ISS. Industry requires the planning stability provided by the extension in order to consider further

investment in microgravity research and transportation services. Commercial LEO development, spurred in part by the continuation of ISS, will also help enable exploration and make NASA resources available for deeper space exploration.

In addition to the United States, the Government of Canada has announced that Canada will continue its participation in the ISS to 2024. There have been multiple public indications that Russia will continue participating in the ISS program through 2024; Roscosmos (the Russian Federal Space Agency) has publicly commented that it expects to receive government authority by the end of the year to continue ISS beyond 2020. The Government of Japan has also indicated that its decision to support ISS operations beyond 2020 will likely be made in the near future after internal government deliberations are completed. The European Space Agency is expected to address ISS operations and utilization beyond 2020 at their ministerial meeting in late 2016. The ISS Partners have expressed support for continuing research on ISS, and see tremendous benefit for extended research opportunities.

As NASA has moved into Station's intensive utilization phase, we have become more cost-efficient in ISS operations. In the FY 2016 President's Budget Request, ISS Operations and Maintenance (O&M) is only 35 percent of the ISS request. The majority of the request, 55 percent, is for ISS Crew and Cargo Transportation. The remaining 10 percent is for ISS Research. Since the ISS was extended to 2020 in 2011, NASA has reduced the ISS O&M budget through a combination of efficiencies in sustaining activities, some content reductions, and cutbacks in operations overhead. While NASA continues to look for further efficiencies, we have already achieved a level of efficiency that allows us to productively operate and sustain the ISS, keep our crews healthy and safe, and support utilization with substantially reduced resources. Ongoing activities to responsibly lower the O&M cost of the ISS include changes to our contracts to incentivize efficiency, lower overhead cost, and apply targeted enhancements in technology investments to reduce manpower-intensive processes. These activities are assumed in the FY 2016 President's Budget Request.

ISS Research

The ISS supports research across a diverse array of disciplines, including high-energy particle physics, Earth remote sensing and geophysics experiments, molecular and cellular biotechnology experiments, human physiology research (including bone and muscle research), radiation research, plant and cultivation experiments, combustion research, fluid research, materials science experiments, and biological investigations. In addition, the ISS is an invaluable platform for technology development efforts. Research and development conducted aboard the ISS holds the promise of next-generation technologies, not only in areas directly related to NASA's exploration efforts, but in fields that have numerous terrestrial applications. The ISS will provide these opportunities to scientists, engineers, and technologists through at least 2024. Beyond being a feat of unparalleled engineering and construction, as well as international collaboration, the ISS is a place to learn how to live and work in space over a long period of time and foster new markets for commercial products and services. Remarkably, 83 countries/areas worldwide have participated in ISS utilization.

NASA's Human Research Program continues to develop biomedical science, technologies, countermeasures, diagnostics, and design tools to keep crews safe and productive on long-duration space missions. The progress in science and technology driven by this research could have broad impacts on Earth as it advances our ability to support long-duration human exploration.

On March 27, 2015, NASA astronaut Scott Kelly and cosmonaut Mikhail Kornienko of Roscosmos launched to the ISS to begin a one-year mission aboard the orbiting outpost. NASA and Roscosmos selected several collaborative investigations for this mission to evaluate the effects of long-duration

spaceflight on humans. Each of the U.S. investigations will be grouped into one of seven categories: functional, behavioral health, visual impairment, metabolic, physical performance, microbial, and human factors. Researchers expect the mission's investigations to provide data on biomedical, performance, and behavioral changes and challenges astronauts may face when they embark on longer-duration missions, like those to an asteroid, Mars, or beyond. Data from the expedition will be used to determine whether there are ways to further reduce the risks on future long-duration missions to an asteroid and eventually Mars.

The investigations involving astronauts Scott and Mark Kelly, who are identical twins, will provide NASA and outside researchers with a genetic blueprint and broader insight into the subtle genetic effects and changes that may occur during long-term (i.e., one year) spaceflight as compared to Earth-based environments. The studies will focus on four areas: human physiology, behavioral health, microbiology/microbiome, and molecular or -omics studies (-omics refers to a system-level approach to studying molecular biology; examples include genomics, proteomics, and metabolomics). Although the investigations conducted on the Kelly brothers are not expected to provide definitive data about the effects of spaceflight on individuals — because there are only two subjects for data collection — they do serve as a demonstration project for future research initiatives. These investigations may identify changes to pursue in research of larger astronaut populations.

NASA is also exploring open-source science where databases are made available to a large number of researchers for investigation. This approach is in contrast to the past practice of one researcher "owning" all of the data from their investigation. This open-science approach shares a large data set of information with researchers for a variety of investigations

A National Laboratory in Orbit

In the NASA Authorization Act of 2005 (P.L. 109-155), Congress designated the U.S. segment of the ISS as a National Laboratory, and directed the Agency to seek to increase the utilization of the ISS by other Federal entities and the private sector. Subsequently, in the NASA Authorization Act of 2010 (P.L. 111-267), Congress directed that the Agency enter into a cooperative agreement with a not-for-profit organization to manage the activities of the ISS National Laboratory. On August 31, 2011, the Agency finalized a cooperative agreement with CASIS to manage the portion of the ISS that operates as a U.S. National Laboratory. CASIS works to ensure that the Station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological, and industrial communities. The goal is to support, promote and accelerate innovations and new discoveries in science, engineering, and technology that will improve life on Earth. NASA's National Laboratory partners can use the unique microgravity environment of space and the advanced research facilities aboard Station to enable investigations that may give them the edge in the global competition to develop valuable, high technology products and services. The National Laboratory will help establish and demonstrate the market for research in LEO beyond the requirements of NASA.

Use of the ISS as a National Laboratory has increased significantly since FY 2012, which was the first full year of operations by CASIS. CASIS is reaching its full allocation of National Lab resources and it expected to continue to do so for the foreseeable future. The growth is coming from non-traditional areas, specifically from the commercial sector. Commercial projects for research and technology development on the ISS National Lab have increased from three in FY 2012 to 107 in FY 2014. This includes such industry leaders as Merck, Novartis, and Eli Lilly. Expanded capabilities, such as the ability to conduct model organism research on the ISS, using rodents as well as other organisms, has helped draw this interest. Commercial efforts have also included perhaps the largest purely commercial provision of services using the ISS, the deployment by NanoRacks of dozens of Dove cube satellites for Planet Labs.

Similarly, use by other Government agencies, including the National Institutes of Health and Department of Defense, has also begun to broaden, totaling 11 investigations in FY 2014. Finally, investigations from academic institutions rose from 31 in FY 2012 to 90 in FY 2014. Grant funding for research through the National Lab continues to grow, from $2.1 million in FY 2012, to $5.9 million in FY 2014. Additionally, NASA is collaborating with CASIS to enable sustained investment and research activities onboard the ISS across industry and other Government agencies that will transcend the life of the Station. The ISS International Partners are also seeking to expand the base of researchers using their assets on the ISS and are very interested in the National Lab model. This will expand research, and commercial participation, in low-Earth orbit.

ISS – Benefits to Humanity

Almost as soon as the ISS was habitable, researchers began using it to study the impact of microgravity and other space effects. In the physical and biological sciences arena, the ISS allows researchers to use microgravity conditions to understand the effect of the microgravity environment on microbial systems, fluid physics, combustion science, and materials processing, as well as environmental control and fire safety technologies. The ISS also provides a test bed for studying, developing, and testing new technologies for use in future exploration missions. Although each Station partner has distinct agency/national goals for ISS research, each partner collectively shares a unified goal to extend the resulting knowledge for the betterment of humanity. In the areas of human health, telemedicine, education, and Earth observations from space, there are already demonstrated benefits. Pharmaceutical development research, Station-generated images that assist with disaster relief and farming, and education programs that inspire future scientists, engineers, and space explorers highlight just some of the many examples of research that can benefit humanity.

ISS crews are conducting human medical research to develop knowledge in the areas of: clinical medicine, human physiology, cardiovascular research, bone and muscle health, neurovestibular medicine, diagnostic instruments and sensors, advanced ultrasound, exercise and pharmacological countermeasures, food and nutrition, immunology and infection, exercise systems, and human behavior and performance. Many investigations conducted aboard ISS will have direct application to terrestrial medicine. For example, the growing senior population may benefit from experiments in the areas of bone and muscle health, immunology, vestibular response and balance, and from the development of advanced diagnostic systems. The ISS requires telemedicine be used to monitor and treat crews. Optical Computerized Tomography (OCT), fundoscopy, and tonometry are now routinely used onboard the ISS to diagnose and monitor any progression of Visual Impairment Intracranial Pressure (VIIP) syndrome. The ISS Ultrasound aides in the remote diagnosis of a variety of conditions ranging from musculo-skeletal issues and abdominal pains to infection of soft tissues. Similar equipment and techniques can be used on Earth to provide medical care to patients without requiring their travel to a hospital or doctor.

The ISS also plays an important role in promoting education in the science, technology, engineering, and mathematics (STEM) fields, inspiring students to pursue scientific and technical careers. Astronauts aboard ISS participate in educational downlinks with schools, and engage in communicating with people around the world using "ham" radio. The ISS Program also conducts experiments that involve student participation. One example is the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) facility. SPHERES are three bowling-ball sized spherical satellites that are used inside the Station to test telerobotics operations in addition to spacecraft formation flight and autonomous rendezvous and docking maneuvers. NASA, along with the Defense Advanced Research Projects Agency, with implementation by the Massachusetts Institute of Technology, has co-sponsored "Zero Robotics SPHERES Challenge" competitions for high school and middle students from the U.S. and abroad. The competitions challenge students to write software code, which is uploaded to the robots on

ISS, and the SPHERES satellites then execute the instructions, in areas such as formation flight and close proximity operations. Student finalists were able to watch their flight program live on NASA-TV.

Conclusion

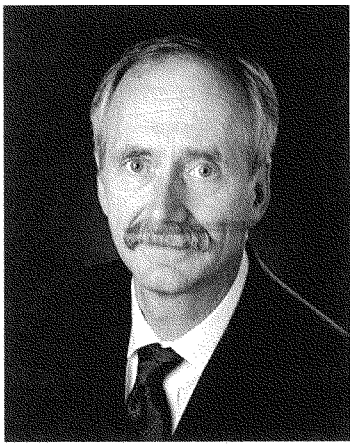
The ISS has now entered its intensive research and technology demonstration phase. Station will continue to meet NASA's mission objective to prepare for the next steps in human space exploration. Closer to home, NASA's National Laboratory partners can use the unique microgravity environment of space and the advanced research facilities aboard Station to enable investigations that may give them the edge in the global competition to develop valuable, high technology products and services. Furthermore, the demand for access to the ISS enables the establishment of robust U.S. commercial crew and cargo capabilities. Both of these aspects of the U.S. segment of the ISS as a National Laboratory will help establish and demonstrate the market for research in LEO beyond the requirements of NASA.

With NASA as the lead integrator on ISS for the international partnership, the ISS allows the U.S. to demonstrate global leadership in human spaceflight and technology development. ISS and the teams that operate it are an amazing global resource.

NASA appreciates this Committee's ongoing support of the ISS as we work together to support this amazing facility which yields remarkable results and benefits for the world.

Mr. Chairman, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.

WILLIAM H. GERSTENMAIER
ASSOCIATE ADMINISTRATOR FOR
HUMAN EXPLORATION AND OPERATIONS



William H. Gerstenmaier is the associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington, DC. In this position, Mr. Gerstenmaier provides strategic direction for all aspects of NASA's human exploration of space and cross-agency space support functions of space communications and space launch vehicles. He provides programmatic direction for the continued operation and utilization of the International Space Station, development of the Space Launch System and Orion spacecraft, and is providing strategic guidance and direction for the commercial crew and cargo programs that will provide logistics and crew transportation for the International Space Station.

Mr. Gerstenmaier began his NASA career in 1977 at the then Lewis Research Center in Cleveland, Ohio, performing aeronautical research. He was involved with the wind tunnel tests that were used to develop the calibration curves for the air data probes used during entry on the Space Shuttle.

Beginning in 1988, Mr. Gerstenmaier headed the Orbital Maneuvering Vehicle (OMV) Operations Office, Systems Division at the Johnson Space Center. He was responsible for all aspects of OMV operations at Johnson, including development of a ground control center and training facility for OMV, operations support to vehicle development, and personnel and procedures development to support OMV operations. Subsequently he headed the Space Shuttle/Space Station Freedom Assembly Operations Office, Operations Division. He was responsible for resolving technical assembly issues and developing assembly strategies.

Mr. Gerstenmaier also served as Shuttle/Mir Program operations manager. In this role, he was the primary interface to the Russian Space Agency for operational issues, negotiating all protocols used in support of operations during the Shuttle/Mir missions. In addition, he supported NASA 2 operations in Russia, from January through September 1996 including responsibility for daily activities, as well as the health and safety of the NASA crewmember on space station Mir. He scheduled science activities, public affairs activities, monitored Mir systems, and communicated with the NASA astronaut on Mir.

In 1998, Mr. Gerstenmaier was named manager, Space Shuttle Program Integration, responsible for the overall management, integration, and operations of the Space Shuttle Program. This included development and operations of all Space Shuttle elements, including the orbiter, external tank, solid rocket boosters, and Space Shuttle main engines, as well as the facilities required to support ground processing and flight operations.

In December 2000, Mr. Gerstenmaier was named deputy manager, International Space Station Program and two years later became manager. He was responsibility for the day-to-day management, development, integration, and operation of the International Space Station. This included the design, manufacture, testing, and delivery of complex space flight hardware and software, and for its integration with the elements from the International Partners into a fully functional and operating International Space Station.

Named associate administrator for the Space Operations Directorate in 2005, Mr. Gerstenmaier directed the safe completion of the last 21 Space Shuttle missions that witnessed assembly complete of the

International Space Station. During this time, he provided programmatic direction for the integration and operation of the International Space Station, space communications, and space launch vehicles.

In 2011, Mr. Gerstenmaier was named to his current position as associate administrator for the Human Exploration and Operations Mission Directorate.

Mr. Gerstenmaier received a bachelor of science in aeronautical engineering from Purdue University in 1977 and a master of science degree in mechanical engineering from the University of Toledo in 1981. In 1992 and 1993, he completed course work for a doctorate in dynamics and control with emphasis in propulsion at Purdue University.

Mr. Gerstenmaier is the recipient of numerous awards, including three NASA Certificates of Commendation, two NASA Exceptional Service Medals, a Senior NASA Outstanding Leadership Medal, the Meritorious Executive Presidential Rank Award, and Distinguish Executive Presidential Rank Award. He also was honored with an Outstanding Aerospace Engineer Award from Purdue University. Additionally, he was twice honored by Aviation Week and Space Technology for outstanding achievement in the field of space. His other awards include: the AIAA International Cooperation Award; the National Space Club Astronautics Engineer Award; National Space Club Von Braun Award; the Federation of Galaxy Explorers Space Leadership Award; AIAA International Award; the AIAA Fellow; Purdue University Distinguished Alumni Award; and Honored at Purdue as an Old Master in the Old Masters Program; recipient of the Rotary National Award for Space Achievement's National Space Trophy; Space Transportation Leadership Award; the AIAA von Braun Award for Excellence in Space Program Management; and the AIAA von Karman Lectureship in Astronautics.

He is married to the former Marsha Ann Johnson. They have two children.

July 2015

Chairman BABIN. Yes, sir. Thank you, Mr. Gerstenmaier. I'll now recognize Mr. Elbon for five minutes to present his testimony.

TESTIMONY OF MR. JOHN ELBON,
VICE PRESIDENT AND GENERAL MANAGER,
SPACE EXPLORATION,
THE BOEING COMPANY

Mr. ELBON. Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee, on behalf of The Boeing Company, thank you for the opportunity to testify today to provide an update on Boeing's role in the International Space Station. And Mr. Chairman, as one of your constituents, congratulations on your selection to lead this important Committee.

Boeing is extremely proud to have supported NASA in the design, integration and assembly of the ISS. As NASA's prime contractor, Boeing delivered the U.S. elements of the ISS and provided system integration for the stage-by-stage assembly on orbit of all U.S. and international elements. We continue in the ISS sustainment role today.

On November 2, the world will celebrate 15 years of continuous presence in space, human presence in space, with international crews living and working aboard the ISS. At a time when many decry a gap in America's space program as we transition from the Space Shuttle to commercial transportation, we who know ISS know that America and our partner nations are making advances in space every day.

The International Space Station has been recognized as the largest, most complex international scientific and engineering project in history and the world's largest endeavor in space to date. Ongoing improvements are making ISS even better.

The Station brought together hardware and software from 16 countries around the globe and 37 states and more than 10,000 suppliers in our country. About the size of an American football field, the ISS is larger than a six bedroom house and has the internal pressurized volume of a 747.

ISS is an engineering marvel, a beacon for international cooperation, and a shining example of what can be achieved through strong leadership and unity of purpose on behalf of humankind.

As NASA's contractor for sustaining engineering of the ISS, Boeing is responsible for maintaining the Station and ensuring the full availability of the unique research laboratory for NASA, international partners, other U.S. Government agencies and private companies. In performing this role, we continue to work with NASA to reduce the costs of sustaining the International Space Station.

Over the past ten years, we have reduced the cost of our sustainment role by more than 30 percent. These savings has enabled NASA to fund ISS improvements such as the NASA Docking System, the critical component supporting the increase in the number of commercial vehicles visiting the Station. These improvements help to keep ISS at peak efficiency today and provide a basis for continuing strong performance well into the future. With NASA, we recently completed a technical assessment of the useable life of major ISS hardware components. Our study indicates that the Sta-

tion will be operable at least through 2028. Long-term viability of the Station is an important factor in continuing to attract researchers, who invest considerable time in preparing their experiments for operation in space.

The continuing on-orbit reliability of ISS and the improvements made to further enhance research capabilities are a boon to maximizing facility utilization. Our work on ISS enables many benefits and improvements both to enable continuing human space exploration and to improve the quality of life here on Earth.

ISS continues to be used for developing multiple technologies to support deep space exploration. NASA is developing highly reliable life support systems to address needs for future exploration habitation systems. The ISS is a test bed for learning how the body reacts to prolonged weightlessness and allows us to develop countermeasures now.

And we are learning self-sustainment skills, such as growing food in space and recycling water. All of these things are important to learn and understand before we explore farther into our solar system.

Research on ISS has led to numerous improvements on Earth, from the medical field, to Earth observations, to providing clean water in underdeveloped countries, to how we diagnose and treat patients in remote areas.

Over the past several years, I've had opportunity to interact with leaders in countries that are not engaged in the ISS or do not have a space program. Without exception, in every one of these conversations about space exploration, these leaders express a strong desire to be involved in space, and more specifically, the International Space Station. They see the value of ISS: to inspire their youth to pursue STEM education, to create economy-expanding high technology industries, and to provide a significant source of national pride. This fresh perspective from leaders outside Station international partnership recognizing the tremendous value of ISS serves as a strong reminder to U.S. leaders and to all who are charged with the care of this national asset and global resource. We must never take what we have in ISS for granted. We must ensure that the International Space Station is well-funded, meticulously maintained and operated, and fully utilized for meaningful, high-value research.

Thank you, and I look forward to your questions.

[The prepared statement of Mr. Elbon follows:]

Testimony of John Elbon

Vice President and General Manager

Boeing Space Exploration

July 10, 2015

Chairman Babin, Ranking Member Edwards, and members of the Committee, on behalf of The Boeing Company, thank you for the opportunity to testify today to provide an update on Boeing's role in the International Space Station (ISS).

Boeing is extremely proud to have supported NASA in the design, integration and assembly of the ISS. As NASA's prime contractor, Boeing delivered the U.S. elements of the ISS and provided system integration and stage-by-stage assembly on orbit of all U.S. and international elements. We continue in the ISS sustainment role today.

On November 2nd the world will celebrate 15 years of continuous human presence in space, with international crews living and working aboard ISS. At a time when many decry a gap in America's space program as we transition from the Space Shuttle to commercial transportation solutions, we who know ISS know that America and our partner nations are making advances in space every day.

Consistent with the Committee's request, I am pleased to share some of these advances as I address current ISS operational capabilities and improvements to maximize ISS utilization, as well as Boeing's role in technical issue resolution in cooperation with NASA and the International Partners.

Current Operational Capabilities.

The International Space Station has been recognized as the largest, most complex international scientific and engineering project in history and the world's largest endeavor in space to date. Ongoing improvements have made ISS even better.

The Station brought together hardware and software from 16 countries, 37 states and more than 10,000 suppliers, often with first-time integration occurring on orbit. About the size of an American football field, the ISS is larger than a six bedroom house and has the internal pressurized volume of a Boeing 747.

An electrical power system with eight miles of wiring receives its power from more than an acre of solar arrays – a surface area that could cover the U.S. House chamber three times. Those same solar arrays make ISS the brightest object in the night sky after the moon. Featuring three dedicated research laboratories – the U.S. Destiny Laboratory, the European Space Agency's Columbus Laboratory, and the Japanese Kibo Laboratory – ISS is the world's preeminent microgravity research facility.

ISS is an engineering marvel, a beacon for international cooperation, and a shining example of what can be achieved through strong leadership and unity of purpose for the benefit of humankind.

As NASA's contractor for sustaining engineering for the ISS, Boeing is responsible for maintaining the station and ensuring the full availability of the unique research laboratory for NASA, International Partners, other U.S. government agencies and private companies.

Operational Efficiencies and Improvements.

Boeing continues to work with NASA to reduce the costs of sustaining the International Space Station. Over the past 10 years, we have reduced the cost of our sustainment role by more than 30 percent.

This savings has enabled NASA to fund ISS improvements such as the NASA Docking System, which includes the International Docking Adapter (IDA) – a critical component supporting the increase in the number of commercial vehicles visiting the Station and enabling NASA and the International Partners to increase the crew size on Station. The crew spends approximately 35 hours a week dedicated to space station science and research. When we increase crew size by one, the research time nearly doubles.

ISS Space to Ground communications channels have been improved, allowing for more real time interaction between crew members performing experiment tasks on-orbit and science experts on the ground. This real-time dialogue enables quick adjustments to research parameters while the experiment is being conducted, providing more meaningful results.

ISS now provides higher quality video downlinks to support more detailed observations and a higher rate data downlink to send more science data to analysts on the ground more quickly. Higher speed data downlinks are particularly important due to the large data sets coming down from ISS.

The ISS power system has been upgraded to 110 VAC. This is important because it allows the use of commercial-off-the-shelf hardware on ISS instead of more expensive custom or highly modified equipment, which can deter prospective researchers. Because 110 VAC is what most ground-based laboratories use, this also allows easy transition of equipment and significantly lowers the cost of laboratory outfitting.

These improvements help to keep ISS operating at peak efficiency today and provide a basis for continuing strong performance well into the future. Boeing recently completed a technical assessment of the useable life of major ISS hardware components. Our study indicates that the Station will be operable to at least 2028. Long-term viability of the Station is an important factor in continuing to attract researchers, who invest considerable time in preparing their experiments for conduct in space.

Maximizing ISS Science and Utilization.

The continuing on-orbit reliability of ISS and the improvements made to further enhance research capabilities are a boon to maximizing facility utilization. Our experiences and investigations on ISS are providing many benefits and improvements both to enable

continuing human space exploration, and also to improve the quality of life here on Earth.

ISS continues to be used for developing multiple technologies for deep space exploration such as critical life support systems and environment monitoring systems. NASA is developing and testing highly reliable life support systems to address needs for future exploration habitation systems. This includes important carbon dioxide removal systems, oxygen generation systems, and the systems needed to monitor and detect things like trace gases, water contaminants and microbes. All of this is critically important to learn on the ISS before we make longer duration missions farther into our solar system, such as future missions to Mars.

To put the distance from the Earth to Mars in perspective, if the Earth were a classroom sized globe, the ISS would be less than a half of an inch from that globe, the Earth's moon would be about 30 feet from the globe, and Mars would be another 10 miles farther away. Testing and learning on the space station – here, close to the resources of home – is proving to be an intelligent early step on the threshold of deeper space exploration.

The ISS is a test bed for learning how the body reacts to prolonged weightlessness, and allows us to develop countermeasures now. We are learning today the effects and extent of bone loss in zero-g. We are also learning the long-term effects on the neuro vestibular system, as well as the impacts to our ocular system.

We are learning self-sustainment skills, such as growing food in space and recycling water. All of these things are important to learn and understand before we explore farther into our solar system.

Research on ISS has led to numerous improvements on Earth – from the medical field, to Earth observations, to providing clean water in underdeveloped countries, to how we diagnose and treat patients in remote areas.

Space station research has led to medication that can help offset the effects of osteoporosis. Space research could also lead to cures for Duchenne Muscular Dystrophy and vaccines for things like staph infection and Salmonella poisoning.

In addition, the technology that went into developing neuroArm, the world's first robot capable of performing surgery inside an MRI, was developed from the Canadarm (developed by MDA for the U.S. Space Shuttle Program) as well as Canadarm2 and Dextre, the Canadian Space Agency's family of space robots performing the heavy-lifting and maintenance on board the International Space Station.

I'd like to expand on some of the ISS science that I find particularly exciting.

WATER RESOURCE MANAGEMENT

Water resource management challenges and hydrological technology development needs are global priorities and provide the opportunity to assert regional leadership.

The challenges of human spaceflight continue to drive innovation in water resource management. Life support systems used in space require water recycling and filtration processes to operate over long periods without potential resupply capabilities. This technology can be applied to address regional water challenges today and in the future.

Similarly to how we reuse waste water on board the ISS, schools in third world countries are utilizing this technology in areas where fresh water is scarce. Last year, a school in Morocco's capitol became the first public facility to use this type of recycling system.

The system relies on a set of organic and ceramic membranes with holes just one ten-thousandth of a millimeter in diameter, which is 700 times thinner than a strand of human hair. These tiny pores filter out unwanted compounds in water, including nitrate – a problematic pollutant that comes from agricultural fertilizers.

Additionally, an orbital complex like ISS can be used for remote sensing purposes, collecting data from space characterizing agricultural productivity, vegetative trends, seasonal ecosystem dynamics, water depth, clarity and sea floor data.

BIOTECHNOLOGY

The biotechnology industry faces significant challenges, given the growing demand for products in the medical, agricultural and environmental fields.

Worldwide research efforts in the areas of molecular and cellular biology to treat and cure human diseases and disorders have exceeded $700 Billion dollars annually. Advances in molecular and cellular biology are essential and necessary to protect and maintain the health of all citizens. New biotech research investigations being conducted in the unique microgravity environment of space are revealing previously unknown biological clues valuable in cancer, genetics and aging research. Unmasking the effects of gravity allows researchers to view proteins as intricate, three-dimensional structures and identify potential medical treatment candidates.

As one specific example, protein molecules crystallized in microgravity have revealed vital structural clues to help identify a viable treatment for Duchenne Muscular Dystrophy (DMD). DMD is the most prevalent form of muscular dystrophy affecting 1 in 3,000 boys (over 50,000 young males in the U.S. today). The average life expectancy of a person with DMD is 25 years and there is currently no cure.

Japanese scientists were able to identify a previously unknown water molecule associated with an inhibitor protein which may be the key to unlocking a potential

cure. In addition to medical applications, advances in Biotechnology research in space may also contribute to development of agricultural land and the reclamation of new lands to satisfy the need for increased agricultural production due to high population growth.

BONE LOSS

In 2010 the FDA approved AMGEN's drug Denosumab, which was used initially for treatment of postmenopausal osteoporosis and subsequently for treatment of bone metastases. Both applications were developed in partnership with the ISS sciences team.

PORTABLE ULTRASOUND TRAINING AND TREATMENT

ISS astronauts were trained to use portable ultrasound to diagnose issues like broken bones and collapsed lungs that might occur on orbit where medical facilities are limited. This same method is now being used to train third-world doctors and care providers to treat patients where modern technology is not available. This training has translated to treatment of more than 40-thousand patients in underserved countries, like Brazil, due to diagnosis through portable ultrasound.

TARGETED METHOD OF CHEMOTHERAPY DRUG DELIVERY; CLINICAL BREAST CANCER TRIALS NOW IN DEVELOPMENT

This treatment has the potential to change how we address cancer—a devastating illness that has touched many of our lives.

Patients receiving invasive cancer treatment must endure ravaging side effects, including nausea, immune suppression, hair loss and even organ failure, in hopes of eradicating cancerous tissues in the body.

Aboard the ISS, a process known as microencapsulation is being investigated, which may be able to more effectively produce tiny, liquid-filled, biodegradable micro-balloons containing specific combinations of concentrated anti-tumor drugs. Using specialized needles, doctors can deliver these micro-balloons, or microcapsules, to specific treatment sites within the patient. Treatments that target cancerous tissues reduce the general toxicity of chemotherapy or radiation to the surrounding healthy tissues. This kind of targeted therapy may soon revolutionize cancer treatment delivery.

Working with NASA and the International Partners to Resolve Technical Issues.

To ensure ISS continues to achieve its science mission, Boeing supports NASA and the International Partners with technical and operations skills for responsive issue resolution.

We work closely with NASA in the ISS Mission Evaluation Room at the Johnson Space Center, providing ongoing mission support for resolution of on-orbit technical and

operational issues. Technical issues are vetted through the NASA flight operations processes, and interdisciplinary problem resolution teams are assigned to investigate root causes and implement solutions.

In addition to the technical support provided by our dedicated ISS personnel, Boeing is able to draw upon technical experts in a full range of engineering and operations disciplines from across the Boeing Enterprise, including our space, defense, and commercial airplanes businesses.

NASA manages the relationship with the ISS International Partners and leads decisions related to technical anomaly resolution. Supporting the NASA role with the International Partners, Boeing maintains international industry relationships that facilitate technical issue resolution.

Because of the ISS, international cooperation remains constant for space and serves as a bridge for other diplomatic discussions. As a leader and the major supporter of the ISS, the United States is in position to continue to champion a global vision for space exploration.

Closing Remarks.

Over the past several years, I've had the opportunity to interact with leaders in countries that are not engaged in the ISS or do not yet have a space program. Without exception, in every one of these conversations about space exploration, people express a strong desire to be involved in space, and more specifically in the International Space Station.

They see the value of ISS – to inspire their youth to pursue STEM education, to create economy-expanding high technology industries, and to provide a significant source of national pride.

For the United States and our International Partners, the ISS provides all these benefits and much more. Fundamentally, the ISS is a one-of-a-kind laboratory facility where researchers are now leveraging the unique microgravity environment of space to revolutionize how we treat medical conditions and manage natural resources. In addition, ISS serves as a valuable prerequisite to advanced space exploration – a place near Earth to test our deep space exploration wings before flying farther beyond low Earth orbit.

Grand as it is, *building* the ISS is not a crowning achievement. We must continue *utilization* of ISS as a practical resource for advancing science, and improving the human condition. And to derive the *full benefit* of ISS, we must use it as a place to ensure our readiness for traveling much farther in space.

We at The Boeing Company are committed to supporting NASA and keeping ISS healthy and continuously capable to support every aspect of its bold mission – improving life on Earth and enabling exploration beyond.

Thank you.

BOEING

Biography

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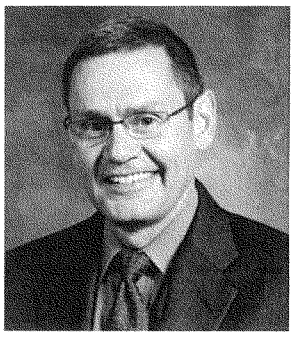

JOHN ELBON

Vice President and General Manager
Space Exploration

John Elbon is vice president and general manager, Space Exploration, a division of Boeing Defense, Space & Security at The Boeing Company. He is responsible for the strategic direction of Boeing's civil space programs, and support of NASA programs such as the International Space Station (ISS), Commercial Crew Development (CCDev) program, and the Space Launch System. He assumed his present position on August 29, 2011.

Elbon served as vice president and program manager for Boeing's Commercial Programs. In this position, Elbon managed Boeing's efforts on NASA's Commercial Crew Space Act Agreements, including the first two phases of the Commercial Crew Development program. He has leveraged innovations and capabilities from across Boeing in the development of crew transportation systems to support NASA and commercial customers in accessing destinations in Low Earth Orbit.

He has been Boeing vice president of Systems Integration for the Army's Future Combat Systems, and the Boeing program manager for several NASA programs including Constellation, ISS, and the, Checkout, Assembly & Payload Processing Services (CAPPS) contract at Kennedy Space Center.

As vice president and program manager of ISS, Elbon led Boeing in its role as prime integrating contractor for NASA's ISS contract to design, develop, test, launch and operate this orbiting facility. The multi-billion dollar contract required the

coordination of several thousand Boeing employees in five major locations as well as subcontractors and suppliers located in 23 states across the United States.

Prior to leading the ISS team, Elbon managed the CAPPS contract at Kennedy Space Center, Fla., responsible for final assembly and testing of elements of the ISS as well as other space shuttle payloads.

He holds a Bachelor of Aerospace Engineering degree from the Georgia Institute of Technology.

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December 2013

Chairman BABIN. Thank you, Mr. Elbon. I now recognize Mr. Martin for five minutes to present his testimony.

TESTIMONY OF THE HONORABLE PAUL K. MARTIN, INSPECTOR GENERAL, NASA

Mr. MARTIN. Thank you for inviting us to be part of the discussion about NASA's challenges in operating and maximizing research on the International Space Station, a very timely topic in light of the loss of three cargo supply flights over the past eight months.

The Office of Inspector General has issued four reports related to the topic of today's hearing during the past two years, including reviews that examine NASA's plans to extend Station operations until 2024 and its contracts with private companies to fly cargo and eventually crew to Station. We have five more reviews related to this topic under way, including an examination of October's cargo resupply failure, NASA's efforts to manage health and behavioral risk for extended space exploration, and challenges to international cooperation in space.

Our audit from last September of NASA's plans to extend the ISS reported that the agency had identified no major obstacles to continued operations through 2024. However, we found NASA must address a series of technical challenges, including ensuring adequate power generation in light of degradation of the Station's solar arrays as well as a limited ability to transport large replacement parts to Station.

While NASA officials estimate an annual ISS budget of between $3 and $4 billion through 2024, we anticipate the cost may be higher. First, much of the projected increase is attributable to higher transportation costs, and we found NASA's estimates for cargo and crew transportation optimistic.

Second, most of the agency's international partners have yet to commit to Station operations beyond 2020, and a decision by one or more not to participate could drive up costs for NASA. As noted in our report, the number one operational risk for the ISS program is ensuring the ability to deliver supplies and astronauts to Station. While NASA is working with two commercial cargo providers for redundancy, flights by Orbital and SpaceX are now on hold pending the outcome of accident investigations and approvals from the FAA and NASA.

In addition to the loss of important supplies, the failed cargo flights have affected NASA research aboard Station in at least three ways: number one, by reducing available crew time due to a temporary delay in returning the Station's crew complement to six astronauts; number two, by increasing cost to replace the lost research; and number three, by delaying return of experiments due to the suspension of flights by SpaceX, the only company capable of bringing cargo back to Earth.

Because NASA uses the ISS as a research platform to study a variety of risks associated with human travel and long-term habitation in space, it is an important part of its plans to send humans beyond low-Earth orbit. As we have reported in the past, utilization of the ISS for research has increased over the years, but several factors continue to limit its full potential. For example, until a sev-

enth astronaut is brought aboard the Station, NASA will not be in a position to maximize crew time devoted to research. In addition, on-board crew will soon devote substantial time to reconfiguring the ISS to accommodate the commercial vehicles NASA hopes will transport astronauts beginning in 2017. To that point, late last year, NASA awarded $6.8 billion in contracts to Boeing and SpaceX to complete development of their spaceflight systems for crew. But NASA's Commercial Crew Program faces several significant hurdles, including unstable funding, the need to provide timely requirements and certification guidance to contractors, and coordination issues with other federal agencies. Given its importance, the OIG recently initiated a follow-up audit to review the status of NASA's Commercial Crew Program.

And that concludes my prepared remarks. Thank you, sir.

[The prepared statement of Mr. Martin follows:]

NASA
National Aeronautics and Space Administration

Office of Inspector General

Testimony before the House of Representatives
Subcommittee on Space, Committee on Science,
Space, and Technology

THE INTERNATIONAL SPACE STATION: ADDRESSING OPERATIONAL CHALLENGES

Statement of Paul K. Martin
Inspector General
National Aeronautics and Space Administration

For Release on Delivery (expected at 9:00 a.m.)
July 10, 2015

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee:

The Office of Inspector General (OIG) is committed to providing independent, aggressive, and objective oversight of NASA programs and personnel. Thank you for this opportunity to appear before the Subcommittee today to discuss the challenges NASA faces in operating the International Space Station (ISS or Station), particularly in light of the loss of three cargo resupply flights during the past 8 months. The OIG has issued four reports related to this topic over the past 2 years, including reviews on NASA's plans to extend Station operations until 2024 and its contracts with private companies to fly cargo and eventually crew to the Station.[1] We plan to issue five additional reports related to this topic later this year, including an audit examining the effects of the October 2014 loss of a commercial cargo resupply mission on Station operations.[2]

The culmination of decades-long international efforts to plan, build, and operate a permanently crewed research platform in space, the ISS is a unique technological achievement that plays a key role in NASA's goal of sending humans to Mars. In November 2013, the ISS completed 15 years of continuous operation in low Earth orbit. With the United States' plan to extend Station operations until 2024, a spacecraft originally designed and tested for a 15-year life span may now operate for 26 years.

While NASA has identified no major obstacles to continued operation of the Station through 2024, in a September 2014 report we found several technical challenges the Agency must address in order to extend ISS operations, including ensuring adequate power generation in light of degradation of the Station's solar arrays.[3] As noted in this report, the number one operational risk for the ISS Program is ensuring the ability to deliver supplies and transport astronauts to and from the Station. The failure of three cargo resupply missions in 8 months – an Orbital Sciences Corporation (Orbital) mission in October 2014, a Russian Progress vehicle in April 2015, and a Space Exploration Technology (Space-X) in June 2015 – underscores the importance of managing this risk. While NASA contracted with two commercial cargo providers to ensure redundancy, both companies' resupply flights are now on hold pending the outcome of accident investigations and approval from the Federal Aviation Administration and NASA to resume cargo missions.

Fortunately, the successful docking of a Russian Progress cargo flight on July 5, 2015, will provide the ISS with much-needed supplies in the short-term until the launch of a Japanese cargo flight in August and NASA's commercial partners return to flight. In the event that Orbital and SpaceX do not return to flight before 2016, NASA may need to make additional operational adjustments, including potentially reducing the number of crew on board the ISS, which in turn would significantly reduce the Station's research capability.

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[1] NASA OIG, "Extending the Operational Life of the International Space Station Until 2024," (IG-14-031, September 18, 2014); "NASA's Management of the Commercial Crew Program," (IG-14-001, November 13, 2013); "NASA's Efforts to Maximize Research on the International Space Station (ISS)," (IG-13-019, July 8, 2013); and "Commercial Cargo: NASA's Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts," (IG-13-016, June 13, 2013).

[2] In addition to a report on the October 2014 mission failure, we are examining NASA's management of ISS contracts, NASA's efforts to manage health and human performance risks for space exploration, challenges to international cooperation in space programs, and NASA's Commercial Crew Program. We also plan to open a review examining the impact of the loss of the June 2015 commercial resupply mission.

[3] NASA OIG, Extending the Operational Life of the ISS.

While it appears the ISS has sufficient food and water to sustain the crew for the next several months, NASA lost important supplies in both the October 2014 and June 2015 failed cargo missions. For example, both flights were carrying supplies for the Station's Environmental Control and Life Support System, including replacement parts for the ISS's water purification system. The flights also carried hardware for the first International Docking Adapter that is necessary to support docking operations for the commercial crew vehicles NASA hopes will begin arriving at the Station in 2017. In addition, the Center for the Advancement of Science in Space (CASIS), which manages non-NASA research aboard the ISS, lost more than $675,000 of research on both flights, including 5 stem cell research projects, a microgravity investigation to help fine tune delivery and dosage of drugs, 8 miniature satellites known as Cubesats, and 10 sets of high school and middle school experiments.

Because NASA utilizes the ISS as a research platform to study and mitigate a variety of risks associated with human travel and long-term habitation in space, the Station is an important part of NASA's plans to send humans beyond low Earth orbit. In our judgment, the recent Orbital and SpaceX launch failures have affected research in three ways: (1) a reduction in available crew time due to a temporary delay in returning the Station's crew complement to six, (2) the cost to regenerate some of the research lost, and (3) a delay in the return of experiments due to the suspension of SpaceX flights, which is the only company capable of returning experiments and other cargo to Earth. Moreover, in our September 2014 report on NASA's plans to extend operation of the ISS, we reported that even if Station operations continue through 2024, NASA will not have sufficient time to address all the health and human performance risks for which the Station is an appropriate research platform.[4] Accordingly, NASA needs to prioritize Station research to address the most important risks in the time remaining. Later this year we plan to issue an audit examining in detail NASA's efforts to address the health and human performance risks associated with long-duration space exploration.

In addition to serving as a platform for NASA research, the Station also provides a laboratory for other government agencies and private entities to advance new technologies in health and medicine, robotics, manufacturing, and propulsion. In August 2011, NASA signed a cooperative agreement with CASIS to manage non-NASA research aboard the ISS. Pursuant to the agreement, NASA provides CASIS $15 million annually and the organization is expected to raise additional funds from private entities and encourage companies to self-fund research. When we interviewed CASIS officials as part of our ISS extension audit, they told us that provisions in the agreement with NASA requiring researchers to assign patent licenses and data rights to the Government were deterring commercial stakeholders from conducting research on the ISS. To address this issue, NASA submitted proposed legislation to Congress in June 2013 that would allow researchers to retain "all rights in inventions made... during the conduct of [Station] activities." To date, the legislation has not moved forward.

While utilization of the ISS for research has increased, several factors continue to pose limits to fully utilizing the Station. First, until a seventh crew member is brought onboard, NASA will not be in a position to maximize the amount of crew time dedicated to research on the Station.[5] Moreover, during 2016 substantial crew time will be devoted to reconfiguring the ISS to accommodate the commercial vehicles NASA hopes will be ready to transport astronauts in 2017.

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[4] NASA OIG, Extending the Operational Life of the ISS.

[5] Although the ISS can support a crew of seven, currently only six individuals can be on Station at one time to accommodate evacuation in case of an emergency. The Russian capsule, which is currently the only vehicle transporting astronauts to the Station, has a three-person capacity and only two Soyuz capsules can be attached to the Station simultaneously.

To that point, securing safe and reliable crew transportation remains a major operational challenge to ensuring the continued effectiveness of the ISS. The fourth and final phase of NASA's Commercial Crew Program began in September 2014 with the award of $6.8 billion in firm-fixed-price contracts to The Boeing Company ($4.2 billion) and SpaceX ($2.6 billion) to complete development and certification of their respective spaceflight systems. Under these contracts, NASA will provide specific requirements for launch systems, spacecraft, and related ground support. The contracts include at least one crewed flight test with a NASA astronaut to verify that the fully integrated rocket and spacecraft system can launch, maneuver in orbit, and dock to the ISS, as well as to validate that all systems are performing as expected. Upon certification, each company will conduct at least two, but as many as six, crewed missions to the Station.

In a November 2013 audit report, we identified four challenges to NASA's Commercial Crew Program: (1) unstable funding, (2) integration of cost estimates with the Program schedule, (3) providing timely requirement and certification guidance to contractors, and (4) spaceflight coordination issues with other Federal agencies.[6] Since that time, NASA has made progress in these areas and expects to address our report recommendations by the end of this month. In May 2015, we began a follow-on audit examining whether the Commercial Crew Program is meeting its planned cost and schedule goals and how it is managing risks and certification requirements.

NASA's annual cost to operate the ISS in fiscal year 2014 was almost $3 billion. Those costs included on-orbit vehicle operations, research, crew transportation, and cargo resupply by U.S. commercial and international partner vehicles. During fiscal year 2016, the ISS Program plans to spend $1.1 billion (almost 36 percent of its budget) on operation and maintenance of the Station and another $1.1 billion on cargo transportation.

Going forward, NASA officials have indicated they intend to maintain the ISS budget between $3 and $4 billion per year through 2024; however, we suspect the cost to NASA will likely be higher. First, much of the projected cost increase can be attributable to higher transportation costs, but we found NASA's estimates for cargo and crew transportation to be optimistic. Second, the Agency's international partners have yet to commit to participating in Station operations beyond 2020. A decision from one or more not to participate could drive up costs for NASA. Given the importance of international cooperation to the ISS and other NASA missions, the OIG is conducting an audit examining NASA's efforts to partner with the space agencies of other countries on science and exploration-related projects.

In addition, as a follow-on to our work on extending the Station to 2024, we are examining NASA's ISS contracts to assess whether the Agency is doing everything possible to avoid incurring unnecessary costs. In the course of this audit, we learned that NASA has taken actions to reduce the operations and maintenance costs of the ISS Program, including competing contracts and taking initial steps to convert portions of the largest ISS contract to a fixed-price vehicle. However, at this point it is unclear to what extent these strategies will result in future cost savings.

In conclusion, the OIG looks forward to continuing our cooperative relationship with NASA, this Subcommittee, and other congressional committees as we examine NASA's effort to address challenges in effectively operating the ISS.

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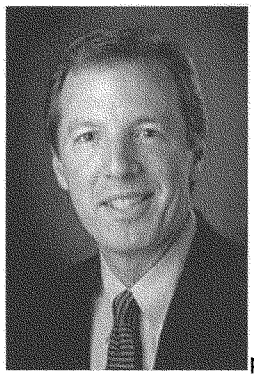
[6] NASA OIG, Commercial Crew Program.

Paul K. Martin
NASA Inspector General



Paul K. Martin was confirmed by the United States Senate as NASA Inspector General on Nov. 20, 2009.

Prior to his NASA appointment, Martin served as the Deputy Inspector General at the U.S. Department of Justice, Office of the Inspector General (OIG). In that capacity, he assisted the Inspector General in managing the audit, inspection and investigative activities of the office's 425 employees. From 2001 to 2003, he served as Counselor to the Inspector General, and from 1998 to 2001 he served as Special Counsel to the Inspector General.

Before joining the Department of Justice OIG, Martin spent 13 years at the U.S. Sentencing Commission in a variety of positions, including 6 years as the Commission's Deputy Staff Director. Martin was one of the Sentencing Commission's first employees when the agency was created in 1985, and helped develop the first set of federal sentencing guidelines.

Martin began his professional career as a reporter with The Greenville News, a daily newspaper in Greenville, SC. He holds a B.A. in Journalism from The Pennsylvania State University and a Juris Doctor from The Georgetown University Law Center.

Martin is married to Rebekah Liu, an attorney working in Washington, DC. A native of Pittsburgh, PA, he and his wife have three daughters.

Chairman BABIN. Thank you, Mr. Martin. And I now recognize Ms. Oakley for five minutes to present her testimony.

TESTIMONY OF MS. SHELBY OAKLEY, ACTING DIRECTOR, ACQUISITION AND SOURCING MANAGEMENT, GOVERNMENT ACCOUNTABILITY OFFICE

Ms. OAKLEY. Good morning, Chairman Babin, Ranking Member Edwards, and Ranking Member Johnson and Members of the Subcommittee. Thank you for inviting me here today to discuss GAO's work on NASA's management of the International Space Station.

As you know, the United States has spent tens of billions of dollars to develop, assemble, and operate the Space Station over the last two decades. The United States could spend billions more in coming years to further capitalize on the investment, given the potential extension of operations to 2024. Today I will discuss three areas: First, NASA's budget for ISS; second, some challenges that could affect increased use of ISS; and finally, steps that NASA and CASIS could take to better document and assess progress in this regard.

NASA continues to make a significant investment in ISS each year. This investment is projected to increase over the next five years mainly because the ISS program will begin to fund commercial crew flights. In 2020, transportation costs will be over 55 percent of the projected $4 billion ISS budget. Unlike transportation costs, costs to operate and conduct research on ISS are projected to remain relatively stable through 2020. NASA officials have indicated that the funding priorities for ISS are crew safety and transportation, maintaining the facility, and finally research. As a result, any increases to transportation costs or operations costs could diminish available funding for research. Furthermore, the potential increases to the ISS budget as a result of the planned extension to 2024 are currently unknown.

Second, NASA and CASIS face several challenges that could negatively affect their efforts to increase use of ISS for science including cargo transportation failures and delays, limited progress in raising additional funding for research, and increased demand for crew time and facilities.

Recent mishaps of the commercial cargo vehicles have had a direct impact on both CASIS and NASA efforts to increase research on ISS. For example, launch failures and delays have already resulted in the loss of CASIS-sponsored research and increased costs by almost $500,000, and let's not forget your crab cakes, Ms. Edwards. Furthermore, additional increases are likely as a result of the most recent failure.

For CASIS, absorbing these increases has and could continue to be challenging because it has thus far made limited progress raising additional funds for science from external sources. For example, in 2014, CASIS had only received a little over $9,000 in contributions. However, CASIS has seen an increase in commitments from external donors. Specifically, in 2014, it received commitments of over $12 million.

CASIS also faces challenges with competition for available crew time and a heavy demand for key facilities which limits the amount and types of experiments that CASIS can bring to ISS.

Crew time is already allocated at or over 100 percent. To address this challenge, NASA and CASIS are dependent on commercial crew providers delivering promised capabilities as planned in 2017. With these capabilities, NASA will be able to add a crew member to ISS who will devote most of his or her time to research, effectively doubling research time.

However, many technical challenges and NASA's ability to fund the Commercial Crew Program could delay these efforts. Finally, even if NASA and CASIS can effectively navigate these challenges, demonstrating a return on investment is very difficult in scientific research and can oftentimes take many years.

In the short term, it is essential that CASIS continues to make progress promoting research and achieving its goal of increased use of ISS.

We reported in April that NASA and CASIS could do more to objectively define, assess, and report on such progress, for example, by assigning measurable targets or goals to its annual performance metrics. NASA and CASIS concurred and agreed to take action in response.

In conclusion, potential extension of ISS to 2024 will likely require significant continued investments. As a result, ensuring that ISS capabilities are being used to support significant scientific gains is critical. Furthermore, demonstrating and communicating the return on investment could help support NASA and CASIS in achieving their shared goal of developing sustained commercial markets in low-Earth orbit.

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee, this concludes my prepared remarks. I'm happy to take any questions that you have.

[The prepared statement of Ms. Oakley follows:]

United States Government Accountability Office

Testimony

Before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives

For Release on Delivery
Expected at 9:00 a.m. ET
Friday, July 10, 2015

INTERNATIONAL SPACE STATION

Challenges to Increased Utilization May Affect Return on Investment

Statement of Shelby S. Oakley
Acting Director, Acquisition and Sourcing Management

GAO Highlights

Highlights of GAO-15-722T, a testimony before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives

July 2015

INTERNATIONAL SPACE STATION

Challenges to Increased Utilization May Affect Return on Investment

Why GAO Did This Study

The United States has spent tens of billions of dollars to develop, assemble, and operate the ISS over the past two decades. NASA plans to spend about $22 billion more from fiscal year 2016 through 2020—with over half of that planned for transportation—on the ISS. In January 2014, the Administration proposed extending the life of the ISS to at least 2024 to take further advantage of the investment in the ISS. Since 2005, Congress enacted several laws to increase utilization of the ISS by commercial and academic researchers. The NASA Authorization Act of 2010 required NASA to enter into a cooperative agreement with a not-for-profit entity to manage the ISS National Laboratory and in 2011 it did so with CASIS. CASIS is charged with maximizing use of the ISS for scientific research by executing several required activities.

This statement will provide an overview of (1) NASA's budget for ISS and the factors affecting budget levels through 2020, (2) several challenges that could impact effective utilization of ISS by both NASA and CASIS, and (3) steps that NASA and CASIS could take to better document and assess CASIS's progress in this regard.

This statement is based primarily on GAO's April 2015 report (GAO-15-397) as well as other prior reports and testimonies. GAO also conducted a limited amount of additional audit work in June 2015 to update certain information.

View GAO-15-722T. For more information, contact Shelby S. Oakley at (202) 512-4841 or oakleys@gao.gov.

What GAO Found

Based on GAO analysis of the National Aeronautics and Space Administration's (NASA) fiscal year 2016 budget estimate, the agency anticipates that the costs to operate, sustain, perform research, and provide crew and cargo transportation to the International Space Station (ISS) are projected to increase by almost $1 billion—or almost 53 percent—from fiscal year 2015 to fiscal year 2020 when the projected costs are expected to exceed $4 billion. The majority of the total projected cost increase for ISS is attributable to commercial crew and cargo transportation. The budget for ISS cargo and crew transportation is currently planned to increase by over $700 million from fiscal year 2016 to fiscal year 2020—or over 55 percent of the total ISS budget—which includes the purchase of six Russian Soyuz seats in 2018 and commercial crew missions beginning in fiscal year 2019. The costs to operate the ISS and perform research are expected to be stable with only slight increases through fiscal year 2020.

NASA and the Center for the Advancement of Science in Space (CASIS)—a non-profit entity selected to manage non-NASA research on the ISS National Laboratory—must overcome several challenges to increase utilization and achieve a better return on investment. NASA and CASIS officials told GAO that the ISS will be challenged to meet an expected increase in demand for crew time and certain research facilities. Securing cargo transportation has also presented challenges. CASIS-sponsored researchers have experienced cost increases of almost $500,000 because of a cargo resupply launch failure in October 2014 and delays to other cargo resupply missions. GAO found that absorbing the increased cost has been a challenge for CASIS given its limited research budget and it could be faced with additional cost increases given the June 2015 launch failure of another cargo resupply mission.

In April 2015, GAO found that CASIS had taken steps to manage and promote research activities on the ISS National Laboratory, but that CASIS and NASA could do more to objectively define, assess, and report progress toward increased utilization. While CASIS had established annual metrics, it did not establish measurable targets for these metrics. GAO has previously reported that performance metrics should have quantifiable targets to help assess whether overall goals are achieved. Consequently, GAO recommended that the ISS program and CASIS develop measurable targets for CASIS's metrics for fiscal year 2016 and beyond. NASA concurred with this recommendation and indicated that these targets should be established by the end of 2015. GAO's April 2015 report also found that while NASA performs an annual assessment of CASIS's performance, the assessment is not documented. This type of documented information can support future assessments of return on investment. GAO recommended that NASA document the annual program assessment of CASIS performance. NASA concurred with this recommendation and plans to take action in response to CASIS's 2015 annual report. Because CASIS is allocated at least 50 percent of ISS research capacity, ensuring that CASIS continues to make progress promoting research activities and achieving its goal to increase utilization of ISS is essential to demonstrate a return on investment for the tens of billions of dollars already invested and that will continued to be invested in ISS.

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee:

Thank you for the opportunity to discuss our work on the National Aeronautics and Space Administration's (NASA) management of the International Space Station (ISS). The United States has spent tens of billions of dollars over the past two decades to develop, assemble, and operate the ISS, which has been used as a manned research outpost continuously for over 14 years. NASA plans to spend about $22 billion more from fiscal year 2016 through 2020—with over half of that planned for transportation—to enable further scientific research the agency views as critical to future human space activities. In January 2014, the Administration proposed extending the life of the ISS by a minimum of 4 years to at least 2024 to take further advantage of the investment in the ISS. Congress enacted several laws to increase utilization of the ISS by commercial and academic researchers.[1] In response to direction in the NASA Authorization Act of 2010, in 2011 NASA selected the Center for the Advancement of Science in Space (CASIS), a non-profit entity, to manage non-NASA commercial and academic research aboard the ISS National Laboratory. Because CASIS is allocated at least 50 percent of ISS research capacity and was created to maximize the value of the ISS investment, future success of the ISS as a research platform is partially dependent on CASIS's success.

My statement today will provide an overview of NASA's budget for ISS and the factors affecting budget levels through 2020. In addition, my statement will also focus on several challenges that could impact effective utilization of the ISS by both NASA and CASIS as they continue their efforts to demonstrate that the research and technology development performed aboard the ISS National Laboratory benefits life on Earth and develop commercial markets that can be sustained in low-Earth orbit. Finally, I will discuss steps that NASA and CASIS could take to better document and assess CASIS's progress in this regard.

[1]Commercial Space Act of 1998, Pub. L. No.105-303, § 101; National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No.109-155, § 507; and National Aeronautics and Space Administration Authorization Act of 2010, Pub. L. No. 111-267, § 504.

In preparing this statement, we primarily relied on work conducted to support our April 2015 report.[2] Additionally, we relied on our prior reports and testimonies, including those related to CASIS's management of the ISS National Laboratory, the agency's acquisition approach for commercial crew transportation, and ISS sustainment and utilization.[3] Information on our scope and methodology is available in the reports cited in this statement. We also conducted a limited amount of additional audit work in June 2015 to update information on CASIS's efforts to increase utilization of the ISS and planned commercial crew and cargo partner missions. The work upon which this statement is based was performed in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient and appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The ISS supports research projects with state of the art facilities for Earth and space science, biology, human physiology, physical science, and materials research, and provides a platform to demonstrate new space-related technologies. The ISS currently has three crew members in the U.S. operating segment who, according to NASA officials, devote a total of approximately 35 hours per week to conduct research. The remaining crew time is used for operations and maintenance of the ISS, training, exercise, and sleep.

[2]GAO, *International Space Station: Measurable Performance Targets and Documentation Needed to Better Assess Management of National Laboratory*, GAO-15-397 (Washington, D.C.: April 27, 2015).

[3]GAO, *NASA: Significant Challenges Remain for Access, Use, and Sustainment of the International Space Station*, GAO-12-587T (Washington, D.C.; March 28, 2012); *International Space Station: Approach for Ensuring Utilization through 2020 Are Reasonable but Should be Revisited as NASA Gains More Knowledge of On-Orbit Performance*, GAO-12-162 (Washington, D.C.; December 15, 2011); and *National Aeronautics and Space Administration: Acquisition Approach for Commercial Crew Transportation includes Good Practices, but Faces Significant Challenges*, GAO-12-282 (Washington, D.C.: December 15, 2011).

Congress Directs Changes in Management of the ISS

Since 2005, Congress has directed several changes regarding the management and utilization of the ISS. For example, the NASA Authorization Act of 2005 designated the U.S Operating Segment of the ISS as a national laboratory and the NASA Authorization Act of 2010 directed the NASA Administrator to provide initial financial assistance and enter into a cooperative agreement with a not-for-profit organization to manage the activities of the ISS National Laboratory for non-NASA utilization of the ISS research capabilities and available facilities.[4] The 2010 act also requires the ISS National Laboratory-managed experiments to be guaranteed access to and use of at least 50 percent of the U.S. research capacity allocation including power, facilities to keep experiments cold, and requisite crew time onboard the ISS through September 30, 2020. Our April 2015 report provides a synopsis of these legislative actions.[5]

In August 2011, after a competitive process, NASA signed a cooperative agreement with CASIS, a not-for-profit entity, to manage the activities of the ISS National Laboratory through September 30, 2020.[6] CASIS is bound by the responsibilities outlined in the cooperative agreement, which tasks it with maximizing the value of the ISS National Laboratory by stimulating interest and use of the ISS for scientific research by directly soliciting potential users and fostering a market to attract others. CASIS is also charged with maximizing the use of the ISS for advancing science, technology, engineering, and mathematics education. Pursuant to the cooperative agreement, NASA will provide CASIS $15 million annually through 2020, of which it will seek to award at least $3 million in research grants. CASIS officials have stated that the remainder of NASA funding is used for infrastructure and direct costs such as labor and travel-related expenses. Further, CASIS is also responsible for soliciting non-NASA funding for research by targeting various sources.

[4]Pub. L. No.109-155, § 507 and Pub. L. No. 111-267, § 504.

[5]GAO-15-397.

[6]The Administration recently proposed extending the operational life of the ISS from 2020 to at least 2024. Our prior work has shown that it is technically feasible to extend the ISS operational life to at least 2028.

NASA Is Taking Steps to Establish Commercial Transportation Capability

In 2005, NASA established the Commercial Crew and Cargo Program to facilitate the private demonstration of safe, reliable, and cost-effective transportation services to low-Earth orbit and encourage innovation in the private sector. The goal of this program is to enable the government to buy both cargo and crew commercial transportation services at a reasonable price. NASA is procuring cargo transportation to the ISS through a commercial resupply services contract that was signed with Orbital Sciences Corporation (Orbital) and Space Exploration Technologies Corporation (SpaceX) in 2008. As of April 2015, SpaceX has launched six successful resupply missions and Orbital has launched two successful resupply missions. Orbital and SpaceX are scheduled to provide 8 and 15 resupply flights, respectively, through December 2017, although the number of Orbital flights may be modified. Orbital resupply flights to the ISS were deferred pending a review of a launch failure that occurred during a resupply launch in October 2014, which resulted in the loss of that mission. According to NASA officials, both Orbital and NASA are still reviewing the mishap and have not provided final reports as of June 2015. The ISS program anticipates that Orbital will resume missions by the end of 2015; however, the flight will use an Atlas rocket to launch a Cygnus spacecraft instead of Orbital's Antares launch vehicle. In late June 2015, SpaceX experienced a launch failure during a cargo resupply launch that resulted in the loss of that mission. NASA is currently evaluating the impact this recent launch failure will have on the ISS program. In September 2014, NASA released a request for proposals for its Commercial Resupply Services 2 (CRS2) requirements, which would result in a follow on contract to the Commercial Resupply Services contracts that were awarded to SpaceX and Orbital in December 2008. NASA expects to award CRS2 contracts in September 2015 for cargo transportation services beginning in 2018, about 4 months later than anticipated.

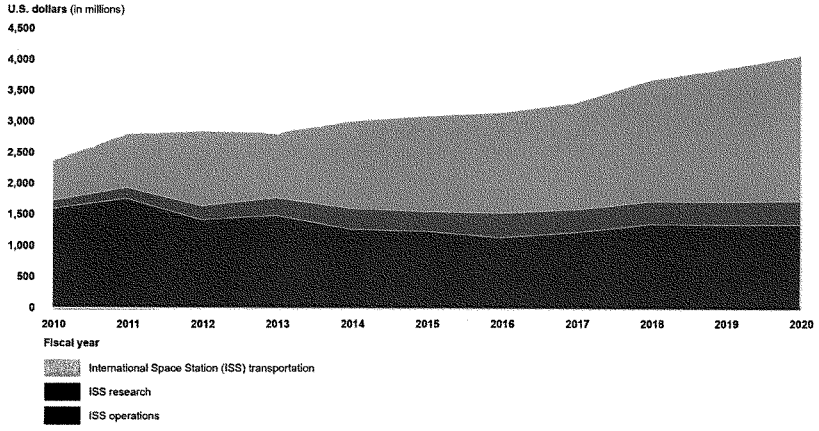
NASA has relied upon Russia to provide crew transportation to and from the ISS since the retirement of the Space Shuttle in 2011. NASA has purchased crew launches from Russia through 2017 and crew rescue and return through mid-2018. NASA purchases seats—at a cost of over $65 million each in 2015—aboard Russian Soyuz space capsules. To support its goal of obtaining low cost domestic crew transport, in September 2014, NASA awarded contracts to The Boeing Company (Boeing) and SpaceX to develop a capability to transport astronauts to and from the ISS. Those awards include a minimum of two to a maximum of six crewed service missions per provider. The Commercial Crew Program, which is outside of the ISS program, is currently responsible for the cost to develop this capability and will also fund one crewed service flight per provider. ISS

program officials have stated that they expect the first service flights to take place in fiscal year 2018. The ISS program will fund the remaining service flights. NASA expects this capability to be available in fiscal year 2018; however, it is unclear whether those vehicles currently in development under the commercial crew program will be ready in time. Once this capability has been established, NASA plans to increase the number of astronauts in the U.S. operating segment of the ISS from three to four.

ISS Budget Projected to Rise to Account for Increasing Transportation Costs while Operations and Research Costs Remain Stable

NASA makes a significant investment in the ISS program each year. Based on our analysis of NASA's fiscal year 2016 budget estimate, the agency anticipates that the costs to operate, sustain, perform research, and provide crew and cargo transportation to the ISS are projected to increase by almost $1 billion—or almost 53 percent—from fiscal year 2015 to fiscal year 2020 when the projected costs are expected to exceed $4 billion. See figure 1 for ISS funding from fiscal year 2010 through fiscal year 2020.

Figure 1: International Space Station Funding by Budget Element for Fiscal Years 2010 through 2020



Source: GAO presentation of NASA data. | GAO-15-722T

The majority of the total projected cost increase for ISS is due to the ISS program's need to pay for commercial crew and cargo transportation. The budget for ISS cargo and crew transportation is currently planned to increase by over $700 million from fiscal year 2016 to fiscal year 2020, at which point it will comprise over 55 percent of the total ISS budget. ISS program officials told us that in fiscal year 2017, the program will begin to fund commercial crew missions that are expected to take place in fiscal year 2019.[7] NASA has also initiated steps to purchase six Soyuz seats from Russia for flights to the ISS in 2018, the cost of which ISS program officials said was accounted for in the projected transportation costs. If NASA determines that domestic commercial entities are able to fulfill crew transportation requirements in 2018, those vehicles will become NASA's

[7]According to ISS officials, the Commercial Spaceflight Program will fund the first flight for Boeing and SpaceX and the ISS program will then fund the second and any subsequent crewed flights.

primary transportation source to the ISS and the Soyuz seats purchased may then be utilized as backup transportation or to augment future ISS needs.

Based on our analysis of NASA's fiscal year 2016 budget estimate, the cost to operate the ISS is expected to be relatively stable with only slight increases through fiscal year 2020. The ISS operations costs decreased $500 million—or 30 percent—from a peak in fiscal year 2011 through fiscal year 2015. Operations costs are expected, however, to increase by approximately $130 million from fiscal year 2017 through fiscal year 2020, which NASA officials attribute in part to inflation and the addition of the fourth crew member. Our past work on Department of Defense (DOD) aircraft systems similarly found that operations costs can increase over time.[8] There may be other factors that could increase operations costs for the ISS over time such as the need for additional spare parts and mitigations needed for structural issues. The ISS program has implemented a number of initiatives that have yielded cost savings or containment. For example, NASA reduced operations costs by scaling back ISS program and contractor workforce levels and by combining several contracts. The NASA Inspector General currently has ongoing work assessing NASA's efforts to combine and consolidate ISS contracts for operations and maintenance.

NASA also projects that the cost for the ISS Research account will remain stable through fiscal year 2020, when research costs are expected to be about 9 percent of total ISS projected costs. Within this account, NASA provides limited funding to CASIS—$15 million per year—of which a minimum of $3 million is to be used to sponsor non-NASA research aboard the ISS by commercial, academic, and other government agency users. Although NASA research costs are projected to remain stable, CASIS sponsored research is not limited to this $3 million minimum. For example, our analysis of CASIS information shows that CASIS has averaged more than $4.3 million in grants paid out to researchers each fiscal year since 2012 and has paid over $15 million to its grantees through March 2015.

[8]GAO, *Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapons Systems*, GAO-10-717 (Washington, D.C.: July 20, 2010).

NASA and CASIS Face Challenges to Increase Utilization and Sustain the ISS Which Could Affect Return on Investment

As we reported in April 2015, NASA and CASIS must overcome several challenges to increase utilization and sustain the ISS until 2024 and achieve a better return on the investment. According to NASA and CASIS officials, as CASIS increases the number of experiments for the ISS National Laboratory, the demand for crew time and certain research facilities aboard the ISS is expected to increase and officials project the ISS National Laboratory will be challenged to meet that demand. NASA officials told us that while the demand for crew time is currently manageable, it remains allocated at or near 100 percent, as the three crew members on the U.S. segment of the ISS utilize most of the 35 hours scheduled per week to conduct research. Crew time for research is expected to double on the ISS National Laboratory once the crew increases from three to four astronauts in fiscal year 2018 because, according to NASA officials, the additional crew member will devote most of his or her time to research. NASA's ability to support increased utilization through an additional crew member, however, is reliant on commercial crew providers providing the promised capability and NASA's ability to fund the effort. Both Boeing and SpaceX plan to hold demonstration flights to the ISS in 2017, but risks remain for both contractors.

According to CASIS officials, they have been challenged to raise additional funding from external sources to supplement the amount of funding provided by NASA. CASIS officials attributed this challenge to the fact that CASIS is a new non-profit entity and the value of performing research aboard the ISS has not been fully demonstrated. Although CASIS's business development team is actively identifying partnerships and funding opportunities with commercial and non-profit granting organizations, CASIS officials said that it takes time to identify, develop, and mature these partnerships to result in funding support. Through December 2014, CASIS reported that it had received funding commitments from external sources of approximately $12 million to support its research mission. However, according to CASIS's fiscal year 2014 annual report, published in December 2014, CASIS received contributions totaling only $9,193 in 2014. NASA officials stated that doing research aboard the ISS National Laboratory can take upwards of 2 to 3 years to plan and execute, timelines that are generally not acceptable to commercial companies that desire a more rapid return on their investments. CASIS and NASA officials also told us that the value of doing research aboard the ISS National Laboratory has to be further demonstrated so commercial industries can be convinced it is worth the high investment.

We also reported in April 2015 that the ability to secure cargo transportation for selected research investigations to the ISS is outside of CASIS's control and has presented challenges. NASA provides launch services to the ISS National Laboratory through its commercial resupply services contracts and CASIS receives cargo allocations for its sponsored research. Budget shortfalls due in part to the effects of sequestration and the Orbital launch failure have resulted NASA cancelling 4 of 46 planned cargo flights through 2020. In January 2015, NASA's Aerospace Safety Advisory Panel noted that both commercial cargo launch providers had struggled to meet desired launch dates and that the schedule performance must significantly improve to enable consistent scientific research on the ISS.[9] The panel added that there will be additional pressure on cargo logistics while Orbital works through its plan to resume cargo missions. This pressure will likely be increased because of the June 2015 launch failure of a SpaceX cargo resupply mission. We found that such launch failures and delays have resulted in cost increases for CASIS-sponsored researchers. For example, the rocket launch failure to the ISS in October 2014 resulted in the loss of several CASIS-sponsored research investigations at a total cost of almost $175,000 which includes hardware and materials, labor consulting, and grants. In addition, launch delays for another cargo resupply mission resulted in over $300,000 in cost increases for several researchers. This included costs for additional materials and samples such as biological payloads that have a limited viability or very specific requirements associated with the timing of the payload flight and often require consumables such as gas and water that must be replenished when a launch is delayed. Absorbing the increased cost has been a challenge for CASIS given its limited research budget, but it is addressing the cost increases due to delays by asking researchers that have biological payloads to identify the impact and associated costs for launch delays in their budgets so it can plan for budget reserves, as necessary.

[9]National Aeronautics and Space Administration, *NASA Aerospace Safety Advisory Panel Annual Report for 2014* (Washington, D.C., Jan. 28, 2015). The Aerospace Safety Advisory Panel was established by Congress in 1968 to provide advice and make recommendations to the NASA Administrator on safety matters. The panel reviews safety studies and operations plans and advises the NASA Administrator and Congress on hazards related to proposed or existing facilities and operations, safety standards and reporting, safety and mission assurance aspects regarding ongoing or proposed programs, and NASA management and culture issues related to safety.

To extend the ISS service life to 2024 or beyond, NASA must ensure that spare parts are sufficient and available when needed and that the structures are sound. In December 2011, we found that NASA had a reasonable approach to determine, obtain, and deliver necessary spare parts to the ISS through 2020.[10] At that time, we found that NASA had given equal weight to manufacturers' predictions and actual performance. However, because NASA has generally found failure rates for replacement units to be lower than manufacturers' predictions, over time the resulting estimates could prove to be overly conservative. More recently, the ISS program reported that one part was failing at rates greater than projected and that spares were not available as a result. In December 2011, we recommended that NASA should reassess the relative weight given to original reliability estimates of spares' life expectancies as performance data accumulates. NASA concurred with this recommendation and the ISS program has taken action to revisit to the methods it uses to calculate the need for spare parts for the ISS. NASA performs an annual assessment of the spare parts, which has resulted in the procurement of spare parts based in part on actual hardware performance. In our December 2011 report, we also found that NASA is using reasonable analytical tools to assess structural health and determine whether ISS hardware can operate safely through 2020. On the basis of prior analysis of structural life usage through 2015 and the robust design of the ISS structures, NASA anticipated that—with some mitigation—the ISS will remain structurally sound for continued operations through 2020. At the time of our 2011 review, NASA had assessed only 40 percent, by weight, of the assembled ISS because most of the ISS structures have not been on orbit long enough to accumulate the data needed for analysis. NASA expected to complete ISS structural assessments in early 2016. These are positive steps; however, continued efforts such as this will be important to ensure that processes NASA uses to evaluate the need for spare parts are adequate to operate and sustain the ISS for at least an additional 4 years.

[10]GAO-12-162.

Objective Assessment of Progress Needed to Demonstrate Return on Investment

Despite these challenges, in April 2015, we reported that CASIS had taken steps to carry out its responsibilities to manage and promote research activities on the ISS National Laboratory as outlined in its cooperative agreement.[11] For example, CASIS had identified key research areas and released seven requests for proposals to solicit interest for research projects. While we noted this progress, we found that CASIS and NASA could do more to objectively define, assess, and report progress toward increased utilization. Specifically, we found that while CASIS had established annual metrics that met most of the key attributes of successful performance measures, it did not establish measurable targets or goals for either fiscal year 2014 or 2015 metrics. We have previously reported that performance metrics should have quantifiable, numerical targets or other measurable values, which help assess whether overall goals and objectives were achieved.[12] We concluded that without these targets, NASA and CASIS cannot conduct assessments of CASIS's efforts to increase ISS utilization that are objective, measurable, or conclusive. To enable such assessments, in April 2015 we recommended that the ISS program manager work with CASIS to collectively develop and approve measurable targets for CASIS's metrics for fiscal year 2016 and beyond. NASA concurred with this recommendation and indicated that these targets should be established by December 31, 2015.

Also in our April 2015 report, we found that while NASA performs an annual assessment of CASIS's performance, the assessment is not documented. Federal standards for internal control call for information to be recorded and communicated to management and others who need it to carry out their responsibilities. This type of documented information is important to support decision making and to support future assessments of return on investment. However, without definitive and documented assessment factors, NASA will also be challenged to take action in response to CASIS performance. According to the cooperative agreement between NASA and CASIS, continued funding of CASIS is contingent on the scientific progress of the project and that NASA will assess such progress in fiscal year 2020 to make a determination about whether to extend or terminate the cooperative agreement.[13] We concluded that

[11]GAO-15-397.

[12]GAO, *Tax Administration: IRS Needs to Further Refine Its Tax Filing Season Performance Measures*, GAO-03-143 (Washington, D.C.: Nov. 22, 2002).

[13]The current cooperative agreement includes a provision for extension beyond 2020.

without documentation based on objective measures of performance, NASA lacks support to make such a decision. We therefore recommended that the ISS program manager document the annual program assessment of CASIS performance in order to provide CASIS management actionable information to better fulfill its responsibilities. NASA concurred with the recommendation and stated that officials would begin documenting the agency's annual program assessment in response to CASIS's 2015 annual report. It will be important that NASA and CASIS follow through on their commitments to have objective measures that will enable NASA to measure CASIS's progress to increase utilization and demonstrate the return on the investment of the ISS.

In conclusion, the ISS offers the potential for scientific breakthroughs, a unique test bed for new technologies and applications, and a platform for increased commercial and academic research and NASA has made an important commitment to the future of research aboard ISS by proposing to extend operations to 2024. Key to supporting this commitment is effectively managing the challenges that could affect efforts to maximize the return on investment for the tens of billions of dollars that have been spent on the ISS. Achieving greater utilization of the ISS and its unique capabilities, showing the benefit of commercial and academic research, and demonstrating success to generate increased interest from potential users could help NASA demonstrate such a return. Because CASIS is allocated at least 50 percent of ISS research capacity, ensuring that CASIS continues to make progress promoting research activities and achieving its goal to increase utilization of the ISS is essential. Even with an extension of operations to 2024, CASIS has limited time to demonstrate that the research and technology development performed aboard the ISS National Laboratory benefits Earth and commercial markets can be sustained in low-Earth orbit. By NASA and CASIS working together in the coming years to address challenges that could negatively affect increased utilization of this unique research facility and to identify and document objective measures of success to demonstrate a return on investment, such a return might be realized.

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contacts and Staff Acknowledgments

GAO Contacts	For questions about this statement, please contact me at (202) 512-4841 or oakleys@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this testimony.
Staff Acknowledgments	Individuals making key contributions to this statement include Richard A. Cederholm, Laura Greifner, and Sylvia Schatz.

Shelby S. Oakley

Ms. Oakley currently serves as an Acting Director in the Acquisition and Sourcing Management team at the U.S. Government Accountability Office. Over the past decade, Ms. Oakley has led reviews of the activities of the National Aeronautics and Space Administration with a focus on helping NASA improve its acquisition management practices. Her reviews have covered key aspects of NASA's operations, such as Space Shuttle workforce transition and sustainment of the International Space Station, as well as reviews of all major NASA systems including depth reviews of NASA's human spaceflight programs and the James Webb Space Telescope. Ms. Oakley has been with GAO for 14 years. She earned a Master's Degree in Public Administration from the University of Pittsburgh's Graduate School of Public and International Affairs and received her Bachelor of Arts Degree in both Psychology and Sociology from Washington and Jefferson College.

Chairman BABIN. Thank you, Ms. Oakley. Now I'd like to recognize Dr. Pawelczyk for five minutes to present his testimony.

TESTIMONY OF DR. JAMES A. PAWELCZYK,
ASSOCIATE PROFESSOR OF
PHYSIOLOGY AND KINESIOLOGY,
THE PENNSYLVANIA STATE UNIVERSITY

Dr. PAWELCZYK. Thank you, Mr. Chairman, Members of the Subcommittee, good morning to you. I thank you for the opportunity to discuss the status of research using the International Space Station. It's the only platform of its kind, and it is absolutely essential to NASA's exploration goals.

To prepare for this hearing, you asked four specific questions, and I would like to briefly address each in the time allotted. You asked about opportunities and challenges. Well, the Augustine Commission emphasized three unique stressors that future astronauts will face: prolonged exposure to solar and galactic radiation; prolonged periods of exposure to microgravity; and confinement in close, relatively austere quarters. All of these stressors are present in the ISS environment. Martian operations add more stressors: a dusty, dim, environment and a gravitational field that is a little more than a third of our own. Unless we improve our centrifuge capabilities on the ISS—they are limited at the moment—we risk sending humans to Mars with little or no knowledge of how mammalian biology responds over years in a gravitational field less than Earth's.

Two challenges dominate the landscape, limited crew time and limited access to the ISS. We can reasonably anticipate that competition for time will become worse as the facility ages and demands to perform necessary maintenance become more acute.

Access is really a matter of competing programs. CASIS-sponsored research and peer-reviewed NASA-sponsored research vie for scarce resources. Better coordination between the two entities is needed.

You asked about critical areas of research. The National Research Council's Life and Physical Sciences Decadal Survey, which was completed in 2011 at Congress' request, summarized and sequenced 65 high-priority research tasks. Furthermore, the decadal study created two notional research plans, one with a goal of rebuilding a research enterprise and the other with a goal of a human mission to Mars. More about those goals in just a moment.

You asked about priorities. Well, prioritizing ISS research isn't a new concept. In fact, we've been working on that problem for close to 15 years. But the key question for prioritization isn't scientific, it's programmatic and it's something like this: Shall discovery research or fundamental research or translational research take precedence in the mature years of the ISS research program? The answer to that question has to be provided by government. Once those programmatic priorities are sequenced, can we prioritize the research? Absolutely. The LPS Decadal Survey provided a very detailed scheme and used eight unique criteria to do so.

The process for operations, you were curious about that, is well understood. CASIS receives its 50-percent allocation followed by

human research, then technology demonstrations, and what resources remain are devoted to biology, physical sciences, and the Science Mission Directorate.

You asked about implications for extension and criteria that Congress should consider. I think one of the first tests that Congress should apply can be answered with a simple yes or no question. Is NASA prepared to operate a robust research program through 2024? And in my opinion, the answer is an unqualified yes, exclamation point. Absolutely. The transformation of this organization in the past five years has been nothing short of remarkable in the life and physical sciences. I've provided seven examples of that in my written testimony. But there are large knowledge gaps for Mars missions that will be one year or longer. The IG recently reported on this topic, and there are four areas where I'd like to see the report go a little bit further. First, the IG found that extension to 2024 wouldn't provide enough time to mitigate 13 human health risks for a Mars mission. I'm not quite prepared to accept that conclusion. There's simply too many degrees of freedom to establish useful risk criteria at this point in time. These risks need the context provided by a thorough task analysis of future Martian operations.

Second, the report didn't address powered down mass to any great extent, and we may need powered sample return for additional research tasks.

Third, the IG emphasized average crew time as a metric to quantify research utility. It's a good metric, but I'm not sure it goes far enough. I think we need to work on the concept of efficiency and evaluate and improve the efficiency of the research time we have.

And finally, the IG noted that research time is constrained with a six-person crew. We need that seventh member.

So my top recommendations are the following: Prioritize the programmatic goals, review the essential resources for extended mammalian research, including that seventh crew member, a scientist astronaut whose nominal responsibility is research, and finally to extend biological experiments to cover a substantial portion of mammalian life cycle and incorporate Martian gravity equivalents wherever possible. Given those sufficient resources, I am very optimistic that NASA can deliver another decade of rigorous translational research.

I sincerely thank you for your support of the program and the opportunity to appear.

[The prepared statement of Dr. Pawelczyk follows:]

Statement by

James A. Pawelczyk, Ph.D.
Associate Professor of Physiology, Kinesiology and Medicine
The Pennsylvania State University

Before the

Subcommittee on Space
Committee on Science, Space, and Technology
United States House of Representatives

The International Space Station: Addressing Operational Challenges

July 10, 2015

Abstract

During this decade of International Space Station (ISS) operations, NASA has made enormous strides to develop and implement a research program that will take humans to Mars. The evolving exploration architecture incorporates a space life sciences strategy aligned with the National Research Council's recent Life and Physical Sciences Decadal study. Research remains constrained by competing priorities, limited funding, available crew time, and powered up- and down-mass. To capitalize on the remaining life of the ISS, and to keep the United States at the forefront of exploration, a robust ground-based research program that fully engages the help of the external science community must be aligned with a flight research program designed to keep humans healthy in fractional gravity environments for periods of time exceeding a year. By doing so we can achieve the penultimate goal of the ISS program; to endow future space explorers with the knowledge, skills and abilities to operate independently from Earth.

Mr. Chairman and Members of the Sub-Committee:

Good morning. I thank you for the opportunity to discuss the status of research using the International Space Station. I have been a space life sciences researcher for more than 25 years, regularly funded by grants from NASA. From 1996-1998 I took leave from my academic position at The Pennsylvania State University to serve as a payload specialist astronaut, or guest researcher, on the STS-90 Neurolab Spacelab mission, which flew on the space shuttle Columbia in 1998. I have more than 15 years of experience advising

NASA on its life sciences strategy and portfolio, either as a direct consultant or through committees of the National Academies of Science, Engineering and Medicine. I help evaluate NASA's Bioastronautics Research Program for the Institute of Medicine. I am also inaugural member of the National Research Council's (NRC) newly constituted Committee on Biological and Physical Sciences in Space (CBPSS). Part of our charge is to monitor NASA's progress in implementing the recommendations contained in, "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," published by the NRC in 2011[1].

The ISS provides a unique platform for research. Past NRC studies have noted the critical importance of the ISS's capabilities to support the goal of long-term human exploration in space. These capabilities include the ability to perform experiments of extended duration, the ability to continually revise experiment parameters on the basis of previous results, the flexibility in experimental design provided by human operators, and the availability of sophisticated experimental facilities with significant power and data resources. The ISS is the only platform of its kind, and it is essential that its presence and dedication to research for the life and physical sciences be fully employed for as long as it is practicable to do so.

To prepare for this hearing, you asked four specific questions:

1. What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?
2. What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?
3. How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?
4. What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?

In the time allotted, I'd like to share my generally positive view of NASA's progress, and provide some specific suggestions to maximize the use of this extraordinary national resource that has been orbiting our planet every 90 minutes for the past 17 years. My comments will not stray far from my areas of expertise in the life sciences, but many of them should be applicable to the physical sciences as well.

1. *What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?*

The 2009 report from the Review of U.S. Human Spaceflight Plans Committee (the "Augustine Commission") emphasized that future astronauts will face three unique stressors[2]:

- prolonged exposure to solar and galactic radiation;
- prolonged periods of exposure to microgravity; and,

[1] http://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences
[2] http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

- confinement in close, relatively austere quarters along with a small number of other crew members who must live and work as a cohesive team for many months while having limited contact with their family, friends and culture.

All of these stressors are present in the ISS environment. Martian operations add more stressors: a dusty, dim, energetic environment and a gravitational field that is a little more than a third of our own. Research to address the biological response to fractional gravity is perhaps the area most impacted by changes to the ISS program over the decades. Unless we improve our research centrifuge capabilities on the ISS, we accept a risk of sending humans to Mars with little or no knowledge of how mammalian biology responds in a gravitational field other than Earth's.

My colleagues in the science community report that two of the major challenges to the biology research portfolio are limited access to the ISS and limited crew time. Some types of research, particularly that employing small mammals, is very time consuming to execute. Animal husbandry for a single rodent experiment can easily outstrip available ISS crew time for research during an increment. We can reasonably anticipate that competition for crew time will become worse as the facility ages, and demands on crew time to perform necessary maintenance become more acute.

Access to the ISS for research is not just a matter of access to space, it is a matter of competing programs. ISS research time is allocated in roughly equal proportions between NASA sponsored, peer-reviewed science and projects sponsored by the Center for the Advancement of Science in Space (CASIS), regardless of what that research might be. The outcome is that National Laboratory research and peer-reviewed, NASA-sponsored research vie for scarce resources such as crew time and positions on the flight manifest; in some cases forcing NASA research to lower-fidelity Earth-based analogs such as bed rest research for muscle atrophy and bone demineralization.

The extension criteria report requested by Congress in the NASA Authorization Act of 2015 creates opportunities to better coordinate NASA and CASIS sponsored research. For example, the ISS Program Office could require an experimental definition phase to maximize science return by combining compatible experiments and expanding biospecimen-sharing experiments to answer the most pressing research questions.

2. ***What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?***

The biological risks associated with exploration-class spaceflight are far from being mitigated. This conclusion is based on analysis of 40 years of NASA-sponsored research.

Since the days of Skylab, NASA-funded investigators conducted an aggressive and successful biological research program that was robust, comprehensive, and internationally recognized. Beginning with those early efforts, and continuing with our international partners on the *Mir* and the ISS, we have built a knowledge base that defines

the rate at which humans adapt during spaceflight up to six-months duration, with four data points exceeding one-year duration. Right now, we are expanding the one-year database! To prepare for Mars, we need to extend the duration further – up to three years - using a combination of astronaut volunteers and small mammals such as rats and mice.

In *Life of Reason*[3], George Santayana warned that, "those who cannot remember the past are condemned to repeat it." We should not forget the precipitous drop in NASA-sponsored research in the first decade of the millennium. The 2001 peak of 1014 separate research tasks was slashed to just 364 in 2010. Space biology and the physical sciences were particularly hard hit, losing about 80% of their research portfolio.

Congress heard the research community's concerns, and we are most thankful for your response. The NRC's Life and Physical Sciences (LPS) Decadal Survey - completed in 2011 as a response to a request from Congress introduced in 2008 authorization language - prompted a sea change in NASA's approach to biological and physical sciences research.

The LPS Decadal summarized and sequenced 65 high priority research tasks. Furthermore, the Decadal study created two notional research plans aligned with specific priorities; one being a goal of rebuilding a research enterprise and the other a goal of a human mission to Mars. More about these goals later.

3. ***How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?***

My response to this question considers general aspects of peer-reviewed research projects that are solicited through open competition. All NASA-sponsored space life and physical sciences research is conducted in this way.

Developing strategic priorities for ISS research is not a new concept. Notable examples from this millennium include:

- The NASA-sponsored Research Maximization and Prioritization Task Force, commonly known as ReMAP, which reported its findings in 2002, representing the breadth of translational research in the biological and physical sciences.
- The ISS utilization studies organized by the National Research Council in 2005.
- Most recently, the Life and Physical Sciences (LPS) Decadal Research Plan; the first decadal survey of NASA's life and physical sciences programs. The guiding principle of the study was, "to set an agenda for research in the next decade that would use the unique characteristics of the space environment to address complex problems in the life and physical sciences, so as to deliver both new knowledge and practical benefits for humankind as it embarks on a new era of space exploration." Furthermore, the LPS Decadal organizers were tasked with

[3] http://www.gutenberg.org/ebooks/15000

establishing priorities for an integrated portfolio of biological and physical sciences research in the decade of 2010-2020.

Why have we asked the prioritization question so many times, and why must we do so again? Because space research informs two broad, often competing, goals: One centers on intrinsic scientific importance or impact; research that illuminates our place in the universe, but cannot be accomplished in a terrestrial environment. The other goal values research that enables long-term human exploration of space beyond low-earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment. Over the past 25 years, other review panels, both internal and external to NASA, have defined similar goals. In the case of the LPS, research was categorized as either (1) required to enable exploration missions or (2) enabled or facilitated because of exploration missions. I prefer the more contemporary synonyms of "discovery" and "translational" research.

Throughout the history of the United States space program both goals have been important, but their relative importance has changed over time. In the early part of the Apollo era, the limited amount of biological and physical research that occurred was focused on the health and safety of astronaut crews in a microgravity environment. Until late in the Apollo program, significant research questions that did not contribute directly to a successful Moon landing received lower priority. In contrast, more regular access to space provided by the space shuttle afforded an opportunity for discovery research to take higher priority; an emphasis that fared poorly in the austere NASA budgetary environment of the mid-2000's.

Thus, the relative priority of these two goals of research - enabling long-term human exploration of space (translation) and answering questions of intrinsic scientific merit (discovery enabled by space research) – shifts according to NASA's programmatic goals.

I make note of the fact that section 201 NASA Authorization Act of 2015 articulates a translational goal of sending humans to Mars, while section 718 emphasizes discovery research. The key question is this: *Shall discovery or translational research takes precedence in the mature years of the ISS research program?* If it is translational research to prepare for a human trip to Mars, then the ISS research portfolio should be tailored accordingly.

The LPS Decadal Survey provides a very detailed scheme to evaluate the importance of proposed research on the International Space Station. It includes eight unique criteria to prioritize research[4], as follows:

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples, Risk Reduction.* The extent to which the results of the research will reduce uncertainty about both the benefits and the risks of space exploration
- *Potential to Enhance Mission Options or to Reduce Mission Costs.* The extent to which the results of the research will reduce the costs of space exploration

[4] http://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples.* The extent to which the results of the research may lead to entirely new options for exploration missions.
- *Relative Impact Within a Research Field.* The extent to which the results of the research will provide full or partial answers to grand science challenges that the space environment provides a unique means to address.
- *Needs that are Unique to NASA Exploration Programs.* The extent to which the results of the research are uniquely needed by NASA, as opposed to any other agencies.
- *Research Programs That Could Be Dual-Use.* The extent to which the results of the research can be synergistic with other agencies' needs.
- *Research Value of Using Reduced-Gravity Environment.* The extent to which the research must use the space environment to achieve useful knowledge.
- *Ability to Translate Results to Terrestrial Needs.* The extent to which the results of the research could lead to either faster or better solutions to terrestrial problems or to terrestrial economic benefit.

Some of these criteria emphasize discovery; others translation. The LPS Decadal Survey prioritizes specific research tasks for each criterion. Again, the Survey appropriately stopped short of weighting or prioritizing criteria against each other because of the programmatic implications. That responsibility – to prioritize either discovery research or Mars - falls largely to the executive and legislative branches. When this question is decided, then the LPS decadal should be a useful tool to program research for the remaining life of the ISS.

Operationally, the ISS Program Office prioritizes all the research to be conducted on each ISS increment. It is a well understood process: CASIS receives a 50% allocation, followed by human research, then technology demonstrations. What resources remain are allocated to the Biological and Physical Sciences Program and the Science Mission Directorate payloads. Both the Human Research and Biological and Physical Science utilize the LPS Decadal criteria for prioritization within their respective programs, but it is not apparent the extent, if any, that LPS Decadal criteria are used to prioritize research across the four programs.

Lastly, it is worth noting that ISS research expenditures, which in FY 2012 constituted about 8%, or $225M, of ISS program costs, are not anticipated to keep pace with overall cost growth of the ISS program.

4. ***What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?***

To evaluate the proposed extension, one of the first tests that Congress should apply can be answered with a yes or no. "Is NASA prepared to operate a robust research program through 2024?" In my opinion, the answer is an unqualified, "yes!" The scope of change

in NASA life and physical sciences in the past four years has been remarkable. Allow me to highlight some notable examples:

- In 2011 NASA reorganized the remnants of a once robust life and physical sciences program to form the Space Life and Physical Sciences Research and Applications Division (SLPSRA). The program is formulated to execute high quality, high value research and application activities in the areas of space life sciences, physical sciences and human research. This reorganization acknowledges – in point of fact, celebrates – both the discovery and translational outcomes of research in the biological and physical sciences.

- Consistent with recommendations in the LPS Decadal, the Biological and Physical Sciences Program has restarted regular research announcements for ground-based and flight experiments. As a rule, these proposals are externally peer reviewed. In FY2014, 30 proposals were funded; 9 of them flight experiments.

- NASA is making greater use of advisors in the National Academies of Science, Engineering and Medicine. In October of 2014 the NRC instituted a new Committee on Biology and Physical Sciences in Space (CBPSS) chaired by Betsy Cantwell (University of Arizona) and Rob Ferl (University of Florida). Part of the Committee's charge is to monitor the progress in implementation of the recommendations contained in, the LPS Decadal.

- The Human Research Program has been aligned with a global exploration strategy. Annual solicitations for research have resumed. The past four quarters for which summaries are available included 212 research publications and more than 277 research proposals.

- We now have an American astronaut on a one-year mission to the ISS, with a unique opportunity to examine his genomic response to this environment.

- The technical content of the Human Bioastronautics Roadmap is in the middle of a five-year review of its 33 risks and 299 research gaps relevant to health and operations in space. The project is being conducted by the Institute of Medicine.

- NASA's Human System Risk Board tracks a subset of 23 risks that require additional research. While all but one have some level of risk mitigation for a one-year stay on the Moon, about half (N=11) do not have any substantive level of risk mitigation for three-year planetary operations.

I think it's reasonable to conclude that NASA has planned its life and physical sciences enterprise to take advantage of ISS research capabilities. The greatest remaining knowledge gaps are for Design Reference Missions on Mars for more than one year.

A recent NASA Office of the Inspector General (OIG) report[5] identified several concerns for continued ISS operations through 2024. There are four aspects of the report that I'd like to address:

First, the OIG found that ISS extension to 2024 could permit NASA enough time to mitigate an additional seven risks of long duration spaceflight. Nevertheless, extended utilization was not expected to fully mitigate another 11 human health risks prior to 2024, and two additional risks could not be mitigated using the ISS. The OIG concluded that NASA, "needs to prioritize its research aboard Station to address the most important risks in the time available." I think this conclusion misses an important point. The likelihood and consequences of at least 11 of the 13 unmitigated risks are dependent on the tasks required of a crew during a Mars Design Reference Mission. Today, there are simply too many degrees of freedom in the task set to establish useful risk criteria. Therefore, before the capabilities of the ISS to mitigate these risks can be evaluated, the risk must be better understood by performing a thorough task analysis of Martian operations.

Second, the report did not address powered down mass to any great extent. This is a critical need when biological samples, including live organisms, are to be returned to the ground for additional study.

Third, the OIG emphasized average crew time as a metric to quantify research utility. Although there are other metrics, including number of investigations, use of allocated space, up-mass, down-mass, and power, thermal, and data usage; in general, NASA does not consider these measures primary indicators of research utilization[6]. What is missing is a method to evaluate the *efficiency* of on-orbit research. Specifically, what percentage of crew time allocated to research is used to conduct it, compared to ancillary functions for such as setting up and stowing equipment? A similar focus has improved extravehicular operations on the ISS. I suspect that we will find that some of the highest priority research, such as studies using small mammals, is also the least efficient; requiring substantial amounts of crew time to set up experiments. If this is true, then increasing efficiency, for example, by improving coordination between NASA and CASIS, could be another way to capture more crew time for research in high priority areas.

Fourth, the OIG notes that research time is constrained with a six person crew. To maximize research utilization, we need to think about a seventh scientist crew member when commercial crew systems can support him or her.

Summary

We desperately need to increase research capabilities in space by translating findings from cell culture to reference organisms and mammalian models such as mice and rats to future flight crews. Translational research is the "gold standard" of the NIH, and it is what the research community, and the American people, should expect from the

[5] http://oig.nasa.gov/audits/reports/FY14/IG-14-031.pdf
[6] https://oig.nasa.gov/audits/reports/FY13/IG-13-019.pdf

International Space Station. We need the capability to house and test model organisms on the ISS for extended periods of time, and whenever possible, to expose them to loading forces that approximate Mars. But equally important, we need adequate time for crew to prepare and conduct these experiments. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an extended human presence in space.

My LPS Decadal Survey colleagues and I contend that NASA can and should continue to restore a high level of programmatic vision and dedication to life and physical sciences research, to ensure that the considerable obstacles to human exploration missions to Mars can be resolved. This will depend on NASA embracing life and physical sciences research as part of its core exploration mission and re-energizing a community of life and physical scientists and engineers focused on both discovery and translational research.

To maximize ISS research, it is of paramount importance …

- That the life and physical sciences research portfolio supported by NASA, both extramurally and intramurally, receive high attention.
- That NASA's research management structure be optimized to meet its discovery research, translational research, and commercialization goals. The utility of a coherent research plan that is appropriately resourced and consistently applied to enable exploration cannot be overemphasized. This will require improved coordination with CASIS.
- That the research portfolio be based on both discovery and translational programmatic priorities, and with specific destination(s) and mission tasks in mind.
- That there is sufficient external oversight to help NASA reach its research goals.

My top recommendations are the following:

- Articulate a timeframe for delivering and completing an operational risk mitigation plan for a multi-year human mission to Mars, and vet both the plan and the timeframe with the external scientific community.
- Review the essential resources for extended mammalian research on the ISS, including a seventh crew member; a scientist-astronaut whose nominal responsibilities are science programming.
- Extend biological science experiments to cover a substantial portion of a mammalian life cycle, and incorporate fractional (Martian) gravity exposure where possible.

Mr. Chairman, given sufficient resources, I am optimistic that NASA can deliver another decade of rigorous translational research. It's what the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the nation's space program, and the opportunity to appear before you today.

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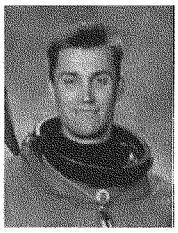

James A. (Jim) Pawelczyk received Bachelor of Arts Degrees in Biology and Psychology from the University of Rochester in 1982, a Masters of Science in Physiology from Penn State University in 1985, and a Ph.D. in Biology (Physiology) from the University of North Texas in 1989. He completed a post-doctoral fellowship at the University of Texas Southwestern Medical Center at Dallas in 1992, then joined the faculty as an Assistant Professor of Cardiology and Bioengineering. In that capacity he served as the Director of the Autonomic and Exercise Physiology Laboratories and a founding member of the Institute for Exercise and Environmental Medicine, a clinical research collaboration between UT Southwestern and Presbyterian Hospital of Dallas. In 1995 he joined the faculty of the Pennsylvania State University where he is now an Associate Professor of Physiology, Kinesiology and Medicine.

Dr. Pawelczyk's research focuses on the dynamic regulation of blood pressure, and how disuse atrophy affects blood pressure regulation. Problems with moment-to-moment regulation of blood pressure lead to orthostatic intolerance, an inability to maintain adequate blood flow to the brain that affects as many as 500,000 Americans. The condition is routinely observed following spaceflight, which Dr. Pawelczyk has studied as a NASA funded investigator for the past six years. In 1995 he was selected as a Payload Specialist for the Neurolab space shuttle mission, and flew aboard STS-90 on the space shuttle Columbia in April and May of 1998. He logged 16 days and 6.4 million miles in space, circling the earth 256 times and conducting neuroscience experiments that addressed changes in the development of the nervous system, balance, blood pressure regulation, sleep, and control movement during spaceflight.

Dr. Pawelczyk assists the formation of U.S. space life sciences strategy. He has testified before the United States Senate Subcommittee on Science and Space, and is an active member of the NASA Advisory Council's Research Subcommittee for Human Exploration, the National Research Council's Committee on Biological and Physical Sciences in Space Board and the Institute of Medicine's Committee on Aerospace Medicine and Extreme Environments. The latter two are part of the National Academies, chartered by Congress to address critical national issues and give advice to the federal government and the public.

Chairman BABIN. Thank you, Dr. Pawelczyk. I thank the witnesses, all the witnesses, for your testimony. Members are reminded that committee rules limit questioning to five minutes. The Chair now recognizes himself for five minutes.

This question will be for Mr. Gerstenmaier and Mr. Elbon. The SpaceX mission had a new commercial crew docking mechanism, water filtration device, and a new spacesuit on board. Can you explain the impact of the loss of these items on the ISS and Commercial Crew Programs? And how do you plan to mitigate these impacts? Mr. Gerstenmaier?

Mr. GERSTENMAIER. Okay. We'll start with the international docking adaptor that's scheduled for Commercial Crew. It was lost. We wanted to have two units on orbit before we began commercial crew flights. We'll still be able to, I believe we'll be able to, support that schedule. We'll take the parts from a third unit that was being assembled as a spare or a backup and work with the contract to go ahead and extend that and get that delivered on time.

The next docking adaptor is scheduled to go in the next several months, and we'll figure out the right cargo flight to take it up. And one docking adaptor will be sufficient to support the Commercial Crew Program. So I think we can accommodate that. The biggest impact to us is the cost associated with now having to manufacture a third unit from the spare parts that remain.

On the multi-filtration beds, we think before the Japanese transfer vehicle flies in August, we should be able to get a new transfer bed manufactured again through the outstanding work of the Boeing Corporation to help us expedite that work, and we've got plans in place to do that.

We've been trending down on the toxic organic compounds on board Space Station, so we're still in a stable configuration with the beds we have on orbit. We'll continue to monitor that carefully. But we should be okay from that standpoint.

The loss of the spacesuit, we will probably now reconfigure one of the spacesuits we had planned on returning on Space Station. We'll do more repairs on it on orbit, and we'll have that space suit available to go do EVAs. And again, we've also put a contract change in place to work with the Orbital Sciences Corporation to look at carrying spacesuits in the future for us.

So I think we've mitigated all three of the concerns that you have. The impacts will be not significant, and we can accommodate them but there are impacts with each one of them.

Chairman BABIN. Thank you. Mr. Elbon?

Mr. ELBON. I'll just add to what Mr. Gerstenmaier said. The most significant involvement from Boeing's perspective is with the docking adapter. The second unit is in Florida and will be ready to fly when we resume flying. And the third unit, the parts are available at our suppliers and in Houston and we're under way putting the plan together to assemble that third unit to replace the one that was lost.

As Mr. Gerstenmaier mentioned, we're working very closely with NASA to understand the water filtration issue and to get those components ready to launch on the next resupply vehicles that go up. So I agree that we're in good shape to support the crew on orbit.

Chairman BABIN. Okay. Thank you. Next question. NASA's Aerospace, and this will be for Mr. Gerstenmaier, NASA's Aerospace Safety Advisory Panel has recommended that as NASA assesses ISS life extension, it should also review the objectives for continued ISS use and clearly articulate them to ensure that the costs and safety risks are balanced. Given that human spaceflight is inherently risky, that risk always needs to be weighed against the value to be gained by the endeavor.

What are NASA's objectives for extending ISS operations through 2024?

Mr. GERSTENMAIER. Again, on the human research front, there's many medical investigations we're looking at that were described by other panel members about the radiation environment, the microgravity environment, and we need to understand those and have those risks mitigated and understood before we're ready to commit to longer endeavors in space. And those are all in plans and are in place. We have detailed investigations and the current one-year expedition on board the Space Station is addressing many of those issues and concerns, and that's moving forward.

Chairman BABIN. Okay. Thank you. And then finally, for Mr. Martin, what insight does NASA have into the mishap, investigations being performed by Orbital ATK and SpaceX? Looking back at the Apollo 1 accident, the Challenger accident, and the Columbia accident, do you believe that the investigations have benefitted from an independent review separate from the contractors or the program?

Mr. MARTIN. Thank you, Mr. Chairman. My understanding is the FAA granted licenses to the private contractors, both SpaceX and Orbital ATK, and under the contract, they are leading the accident investigations. I believe with the Orbital mishap that NASA has a separate review ongoing to try to get to the root cause there. But there is not the same kind of independent accident investigation board if it were a NASA-owned failure. And I think we're currently conducting a review that's going to look at some of the concerns we have about the independence of a contractor-led accident investigation board. But again, pursuant to the contract and the license for the FAA, that's the way it's intended to be.

Chairman BABIN. Okay. Thank you. And that completes my questions. I now recognize the Ranking Member, Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman, and thank you to the witnesses again. Mr. Martin's report of September 2014 found that NASA's estimate for the ISS budget $3 to $4 billion per year through 2024 is overly optimistic. That was reiterated obviously in your testimony. And so I'm just really curious from Mr. Gerstenmaier, if you could talk to us about the basis of your estimates for projected crew and cargo transportation costs to support ISS. And I would note in that for example, there have been three cargo mishaps in the last eight months. Was that factored into your projections for costs? Because it would seem that that alone would then begin to shoot costs up if those kinds of accidents, which one could expect might happen, over the course of operations over another—to 2024. So it would be helpful to know what your basis for those estimated costs are and respond to the challenges that Mr. Martin has laid out in his September 2014 report.

Mr. GERSTENMAIER. We've been looking and working very aggressively to look at cost management and cost control. We've consolidated some contracts into a smaller number of contracts. We also are using competition to attempt to drive down the cost. We're in the process—right now we're in a blackout period of where we're going through a cargo resupply services number two contract award. We've got extremely good competition from that activity, and we believe competition will help us control and hold those costs down.

So I think we're actively working. We're aware of those cost issues and the challenges in front of us. The teams have objective acquisition strategies. We have effective consolidation plans, and we're removing costs from the program as we can. And we believe we can hold those costs down, and we can provide some objective evidence of what we've done and seen in past contracts versus future contract entities.

Ms. EDWARDS. And Mr. Martin, I've heard from Mr. Gerstenmaier, but since your 2014 report, would it still be your assessment that NASA's projections are overly optimistic? And in your analysis, would you factor in three, you know, mishaps, failures, in a year in terms of looking at the costs?

Mr. MARTIN. Yes. I'm not exactly sure whether they factored how many accidents in. But I do think that their cost projections are overly optimistic and continue to be. Over the life of the program, the ISS has shown eight percent increase annually in costs over the life of the program. In fact, from 2011 to 2013, there was a 26 percent cost increase for the ISS. So moving forward, as we go out, as NASA considers extending the life of the Station to 2024, it's projected that in 2024, 59 percent of Station expenses will be for crew and cargo transportation. That's a big piece of the pie.

Ms. EDWARDS. Just curious for all of the panelists, if you look at NASA's rationale for extending to 2024, they include research and technology discoveries that benefit society, enabling human exploration to Mars, establishing crew and cargo to low-Earth orbit, and sustained commercial use of space.

Just curious as to whether any of you believe what NASA's top priority should be. I mean, that's a big list in itself, and it's kind of hard to figure out what should be first versus fourth. Dr. Pawelczyk?

Dr. PAWELCZYK. Thank you very much for that question. And it's a great one, and I think it's an extremely important one for this Subcommittee to take on.

So the three biggies as you mention them really are this idea of discovery science. What are the big science questions that we want to have answered? We may not recognize the utility of those for a period of years. A piece of research equipment that we flew on my mission in 1998 was largely used in last year's Nobel Prize-winning awards. So that's 16 years to recognize some return on that investment, but it's a very important return nonetheless.

There's also translation, this idea of what do we need to do in order to go further. And of course, you mentioned the commercialization aspects. We have contended in the scientific community for many years that it is not our job to sequence those priorities. It is the job of government. It is the job of either the executive

branch or the legislative branch, and I'll leave it up to you to sort out which is which. But I believe you've been pretty clear at this point. When I look at the authorization language for this year, you've said Mars is very important, but it's not an either/or. It's an and. NASA will also maintain a fundamental research program.

So I think you've already told us that Mars is the answer. And when you look at the research that remains to be done, the risks that sit in the red, most of them, and about half of them, are associated with the extended duration on Mars, so a notional mission of approximately three years duration.

I don't know of another research platform that is going to provide us extended research capability to answer those three-year questions. The ISS is our choice for that, and I think that's how it should be used.

Ms. EDWARDS. Thank you. Thank you, Mr. Chairman.

Chairman BABIN. Thank you. And now I'd like to recognize Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman.

Chairman BABIN. Five minutes.

Mr. BROOKS. Yes, sir. Mr. Gerstenmaier, in light of the recent launch failures, is NASA reassessing their insight and oversight approach for the development, production, and operations of commercially provided vehicles that service the International Space Station?

Mr. GERSTENMAIER. As part of the accident investigation with the SpaceX event that occurred, part of our Commercial Crew Program representatives are part of that activity with SpaceX. So they are actively involved in analyzing and understanding what occurred on the cargo vehicle with an eye towards any design changes, any process changes, any hardware changes that need to be made in the crew program. So we're actively involved in transitioning that information from this failure directly into the crew program.

Mr. BROOKS. Thank you, and I appreciate that response, an effort on behalf of NASA. In my experience, NASA has a tremendous amount of insight and expertise, and I would encourage NASA to show the leadership that you indicate they are showing and the management skill that you indicate that they are doing to assist with Commercial Crew so that they can be more successful than they have been most recently.

This question is with respect to Mr. Elbon and Mr. Gerstenmaier. The loss of the SpaceX vehicle two weeks ago has been described as a big loss. Part of that loss was a replacement spacesuit for the International Space Station. What are the implications to the International Space Station program for the loss of this suit?

Mr. GERSTENMAIER. As I described earlier, we'll probably take one of the suits that are on orbit and then refurbish it on orbit instead of returning it to the ground, and then we will develop a capability to transport suits that areon all of our cargo vehicles so that we can bring other suits up to Space Station as needed to support the EVA activity.

Mr. BROOKS. Mr. Elbon, do you have anything to add?

Mr. ELBON. The space suits themselves are not part of our sustaining contract, so I'm not in the middle of working that. We do however help NASA with all the analysis necessary to figure out which activities need to be done on EVA so that we can make sure that Space Station can continue to operate with the capabilities that exist there.

Mr. BROOKS. What was the cost of that lost spacesuit?

Mr. GERSTENMAIER. I don't have a specific cost, and I can take that for the record. We have 13 spacesuits that's available to us. They're from the Shuttle Program, and this was one of those suits. We will not replace that suit. It will just continue to be lost, and it will not be replaced. We have sufficient suits remaining in our inventory to continue to operate safely through the 2024 and beyond timeframe.

Mr. BROOKS. Well, the items that NASA's had on these most recent launches, who is it that is absorbing the cost of those lost items that were being transported to the International Space Station? Is that the commercial crew provider or is that NASA?

Mr. GERSTENMAIER. For the NASA items, the losses are borne by NASA, and we estimate the NASA cargo loss roughly at about $110 million or so on the SpaceX flight. The researchers, they're responsible for their hardware. They bear the loss from the research hardware that was lost, and that's how that splits out.

Mr. BROOKS. Is there going to be any future effort by NASA inasmuch as we're hiring private contractors to require those private contractors to reimburse NASA for equipment and materials lost because the private contractors were unsuccessful in launching their vehicles?

Mr. GERSTENMAIER. Our contracts today have a final milestone payment associated with successful delivery of cargo on orbit. Obviously, they will not receive payment for the accomplishment of that milestone, and we're investigating the advantages and disadvantages of having essentially insurance provided for these other capabilities, or to provide for lost cargo in the future. We haven't made a decision yet on whether that is cost-effective for us or not, but we're taking a look at that to see if it's effective to have insurance or it's better that we just essentially indemnify and the users bear the risk of the loss.

Mr. BROOKS. The monies that will be withheld as payment to the private entity spacecraft providers, is that enough to offset the losses that NASA has incurred?

Mr. GERSTENMAIER. It offsets a portion but not the entire amount.

Mr. BROOKS. So American taxpayers can rest assured then that at least we'll have some recoupment of the losses that American taxpayers have suffered as a consequence of the private sector providers' failure to provide the represented craft?

Mr. GERSTENMAIER. Yes.

Mr. BROOKS. That's all, Mr. Chairman. I yield the remainder of my time.

Chairman BABIN. Yes, sir. Thank you. And I now recognize the Ranking Member from Texas, Ms. Johnson. Is she here?

VOICE. She left.

Chairman BABIN. Oh, okay.

VOICE. It's Mr. Bera.

Chairman BABIN. Mr. Bera from California. I'm sorry.

Mr. BERA. Thank you, Mr. Chairman, and I thank the Ranking Member for this hearing. As a child growing up in Southern California in the aerospace industry in the '60s and early '70s, it was remarkable what we could accomplish as Americans when we dreamt big. And when we think about the International Space Station, it really, truly is an engineering marvel, something that over time has, as the witnesses have noted, 15 years of uninterrupted humans living in space. Remarkable.

When we think about this and when we think about where we want to go, we have to continue to think big as a nation. We have to not be afraid of thinking and addressing the issues, particularly as we dream about human space travel to Mars. We don't know how we're going to get there, but that should not daunt us and that should not stop us, and that should not stop us from making the investments that allow us to continue to incrementally dream big.

Again, that is what we've done throughout our existence as human beings. We've not been afraid to explore. We've not been afraid to ask those questions, and certainly this body has a responsibility to continue to push for the next generation of discovery.

That said, we increasingly move to this coordinated role between what the public invests in partnership with commercialization of space. The last few months have been a bit concerning. We've been fortunate that the accidents did not have human beings on there and only cargo. But as we look at this partnership of commercialization and human space travel and taking human beings to the Space Station and beyond, it is a bit worrisome.

My question, let me direct it to Mr. Martin. In light of these recent accidents and the investigation of these accidents, could you elaborate and maybe expand on NASA's role in making sure there's a transparent investigation? I mean there is some concern if just the commercial entities are investigating without NASA's role.

Mr. MARTIN. Sure, and I think Bill could go into a lot greater detail. Again, under the contracts, since this is a commercial spaceflight, the FAA gives the license, and under the contract, the contractor leads the accident investigation review, unlike a past Challenger accident or something like that where NASA itself would convene an independent accident investigation board.

My sense is that NASA is a member, sort of an advisory member, of Orbital's, and soon to be SpaceX's, accident review boards, but they aren't leading that activity. And perhaps Bill could go deeper on that.

Mr. BERA. That would be great.

Mr. GERSTENMAIER. The NASA team is participating directly along with the FAA team and NTSB on the SpaceX accident board. They developed a fault tree, just as NASA has done, and the way they disposition each fault item is all three entities—NASA, FAA, and NTSB—and SpaceX all have to agree that this item is closed and not contributing to this accident.

So it's by consensus. It's the engineering teams essentially led by SpaceX but fully represented by the government, and the government can say whether we accept or do not accept their explanation for what the root cause was. So it's a fairly effective way for us to

have good insight in. We can do our own independent research on the side and contribute directly to the conclusions and make sure that we are representing the government. So we have the best from the FAA, and the best from NASA, participating in those activities along with the contractor-led activity.

Mr. BERA. And do you feel confident that there's that transparency in there and that we as a body, Congress, will be able to see that transparency and get the full details?

Mr. GERSTENMAIER. So far it's been extremely transparent. It was the same with the Orbital investigation. We had that same transparency with them, and it's been effective for both and we can show direct evidence of where that transparency is and how it's being implemented.

Mr. BERA. Okay. Great. And with that I'll yield back.

Chairman BABIN. Thank you. Now I'd like to recognize the gentleman from Florida, Mr. Posey.

Mr. POSEY. I thank you, Mr. Chairman. Mr. Gerstenmaier, we know that planning for the ISS began 20 years before it was actualized, and now we're less than ten years out from the administration's proposed extension to 2024. Does NASA have plans for some sort of station in low Earth orbit beyond 2024, perhaps some sort of public/private partnerships? Perhaps there are current international partners for an ISS replacement? Or does NASA intend to leave any LEO station entirely to commercial companies?

Mr. GERSTENMAIER. I think at this point we're looking to see if we can leave low-Earth orbit to commercial companies. What we're doing is we're allowing them to do investigations on Station to see if they can get a market return, and it makes sense to do that. Then we believe the agency's role is then to push further out into space to go into the region around the moon we call the proving ground region of space. We will move our research and our endeavors into that further region that helps the agency get prepared to take bigger missions ultimately towards Mars.

So at this point, we're envisioning the low-Earth orbit to essentially be more of a private-sector activity, and we'll use the remaining lifetime of Station to let the private sector understand the benefits of microgravity research to their terrestrial investigations and see if it helps them from a fundamental research standpoint.

Mr. POSEY. Now that's great to hear. Our government is investing in capitals, Orion, Dragon, CST–100, Cygnus. Most capitals are optimized to get crew and cargo back and forth to the ISS. What role will capitals play once the International Space Station reaches the end of its life?

Mr. GERSTENMAIER. Again, for the Commercial Crew Program and also the Commercial Cargo Program, the companies have an interest just beyond the NASA need. They're building these capsules. They'll own the intellectual property. They'll be able to operate these capsules for their own purposes. If this private station we discussed earlier is available, they can use this transportation system to deliver cargo to it. They can deliver a crew to it, et cetera, outside of the government. So this will essentially allow the private sector to go get transportation services on its own from these companies that we've enabled through these initial start-up contracts on ISS.

Mr. POSEY. That's great. The Space Shuttle and X–37, both examples of reusable spacecraft that lands on a runway also have had track records of success. Has NASA completely ruled out the use of reusable runway-capable vehicles for crew or cargo in the future?

Mr. GERSTENMAIER. The simple answer is no. I think in the case of the Orion vehicle, it's geared towards deep space activities where carrying wings makes it very difficult to reenter into the Earth's atmosphere. So the deep space vehicles will typically be a capsule-type vehicle, but for low-Earth orbit transportation, winged vehicles are very nice and have many advantages as we got to see through the Shuttle Program.

Mr. POSEY. Thank you, Mr. Chairman. I yield back.

Chairman BABIN. Thank you, and I'd like to now recognize the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Thank you, Mr. Chairman. Mr. Gerstenmaier, on the one hand we've had the three unfortunate losses that have been previously mentioned. On the other hand, it seems that our commercial space industry is getting ready to grow exponentially, adding great value to our economy and our civilization of the new satellites, internet, space tours of even Mars are talked about.

Can you help us put these accidents in the proper perspective, especially compared to train and airline and automobile accidents, 30,000 deaths last year, by the way, NASA tragedies and all the transportation accidents in history? Are we looking at the relatively two or three that have come up in the right perspective compared to the last 150 years?

Mr. GERSTENMAIER. That's an interesting question. Again, I think the positive thing is that in all three of these cases, there's been no loss of life. So that says our basic processes and procedures are in place. So we protected the public. We protected the launch site. We did the right things.

I think the important thing is to not get so fixated on the problem but how can we learn from this problem, right? As an emerging industry and developing new transportation system, the more we fly, there will be small problems. They're acceptable in this case. As we described earlier, the impacts are not devastating to Station. They hurt research, but they're still recoverable. The real tragedy will be if we don't learn from these events and we don't understand the engineering behind the failures and improve overall the industry.

So I think just as the aviation industry has suffered a lot of failures throughout its history, the reason for its success today and the safety we get in the aircraft industry is a result of lessons learned and those lessons being applied to build better and safer aircraft. We need to do the same thing in the space industry. We need to take this learning from these events, internalize it, not be afraid of it, figure out how to make design changes, change the way we build spacecraft and build a more robust transportation system.

So I see this as a painful but maybe somewhat necessary learning process. It's excellent to learn on cargo. We do not want to learn on crew. We will learn from cargo and apply those lessons to crew.

Mr. BEYER. Well, thank you for your positive and your optimistic attitude which I very much appreciate.

While you have the microphone though, the Aerospace Safety Advisory Panel, ASAP, has identified micro-meteoroid and orbital debris as a top safety risk facing ISS. How does NASA address these concerns about orbital debris?

Mr. GERSTENMAIER. We have shielding on board our Space Station and spacecraft that can protect for some debris. We cannot protect for all debris. We've recently implemented some changes to the Progress vehicle, the Progress launch that just occurred. It had new debris shields on that Progress vehicle. So we're continuing to improve the debris protection capability, and then we actively train on orbit. Just as we train terrestrially for fire drills, et cetera, we train for evacuation drills of Space Station in case we get hit by a piece of micro-meteoroid debris that penetrates a pressure shell. So we're prepared in that event. It is our highest risk when we look across the risk scenario. We protect it with the shielding levels that we can protect for it at this stage of Station's life.

Mr. BEYER. All right. Thank you very much. Dr. Pawelczyk, you testified that during the 2000s, it resulted in NASA's priorities that the life, space life, and physical sciences were particularly hard hit, and a lot of scientists actually left the field. Do you have any concerns about the level of the workforce and expertise in that field today, especially as we get ready to think about man's missions to Mars?

Dr. PAWELCZYK. Thank you very much for the question. I'd say the short answer is no. You're absolutely right that those particular functions were very hard hit. We saw about an 80 percent decrement in the science portfolios in fundamental biology and in the physical sciences. One of the great things that has happened since 2011 is that NASA has reinstituted a ground-based program. If you look at the numbers of people who are applying, they're in the hundreds for solicitation right now. There's active funding that is happening and bringing research up to the Station. So you're starting to see that coming back. But what's even more interesting about it is that you're seeing maybe some of the youngest scientists that have really schooled in the entrepreneurial spirit saying, hey, this is something I'd like to take an opportunity and check out.

You know, the ISS Research Conference this week was about three times bigger than what it was just a year ago. So there's a growing spirit, and we need to continue to feed that spirit, and I think great things will happen as a result.

Mr. BEYER. That's great, and thank you for your enthusiasm. Mr. Chair, I yield back.

Chairman BABIN. Yes, sir. Thank you. Now I'd like to recognize the gentleman from Oklahoma, Mr. Bridenstine.

Mr. BRIDENSTINE. Thank you, Mr. Chairman, and thank you to all of our panelists for coming and testifying before this Committee. Mr. Gerstenmaier, I appreciate your long and distinguished service at NASA going back to negotiating with the Russians on the Mir program and other things in the '90s, and that's really where I'd like to start today. When you think about right now, given the recent accidents that we've gone through, we are seeing how important our reliance is on things like the Russian Progress cargo

spacecraft and of course the Russian Soyuz crew spacecraft. Given how the relationship has changed between the United States and Russia, and we've even heard that, you know, the Russians have talked about pulling out of the International Space Station, what is your judgment on how this relation can go forward? How is it going on the civil space side given the strained relations in other areas? Can you share with us your opinion on that?

Mr. GERSTENMAIER. Yes. On the civil space side, the relationship between the United States or between NASA and the Russians is very strong. We exchange data every day back and forth. We pass many commands to the Space Station, Russian commands through UAS. We use their assets as you've said for transportation reboost. We're very much mutually dependent upon each other for operations in space, and from a technical standpoint, the relationship is extremely strong, extremely transparent in spite of the governmental tensions between the two governments.

So the challenge of human spaceflight kind of transcends a little bit of the toughness of the outside world, and we're working together extremely effectively with the Russians. The recent Progress loss, they've been sharing data with us. We've been working together to actively get ready to go fly crew on the 23rd of this month with the Russians, and they've been open with us, sharing data with us, helping us understand. They understand our needs. So the relationship is extremely strong between the civil space side.

Mr. BRIDENSTINE. How confident are you that they will continue the partnership beyond 2020?

Mr. GERSTENMAIER. Again, I think they're working through their governmental approval process. I think it's likely potentially by the end of this year when their federal space program gets approved that there will be an extension of the Russians to support the Space Station through at least 2024.

Mr. BRIDENSTINE. Mr. Elbon, we have heard the IG has a report indicating that the operations of the ISS are going to become more difficult because of the ability to take replacement parts to the International Space Station. Recently Boeing had a report that might not have contradicted but dealt with some of those issues. Can you share with us the Boeing position? They were suggesting that beyond 2020, things get really difficult. I think your report suggested 2028. Can you share with us how you're dealing with those issues?

Mr. ELBON. Sure. Thanks for the question. The study that we did looked at things like the structural integrity of the elements on board, the ability to survive micro-meteorite kind of penetration and came to the conclusion that through 2028 is completely feasible relative to the hardware that's on orbit.

The other part of the question is what about the logistics resupply to replace boxes that fail on orbit of computers, et cetera, and to supply the crew? And based on the logistics model that NASA's laid out and is using for the procurement of Commercial Resupply Services 2, you know, that kind of volume and up-mass is sufficient to support the logistics resupply that's necessary based on our analysis.

So we think through 2028 is completely doable.

Mr. BRIDENSTINE. Thank you. Thank you for that testimony. Mr. Gerstenmaier, I appreciated Mr. Posey's question about, you know, what comes next after the ISS? Clearly whether it's 2020, 2028, we could lose partners. We don't know when we might lose certain partners. We have to think about what comes next in LEO. And I would like to just follow up with that. Can NASA provide a report to Congress on its plans for a roadmap or a timeline for certifying and testing, you know, a post-ISS station in LEO? And I understand this question was about commercial and things like that, and certainly, that's of interest as well. But it would have to be tested and certified, and NASA would have to be involved, is that correct? Can you provide a timeline to Congress for that?

Mr. GERSTENMAIER. Again, I think the way we need to think about this is that the next private Space Station may not be—in fact, I don't believe it will be as massive or as big as this Space Station we have today, with this International Space Station. There's been discussion by the SpaceX Corporation of using their crew transportation modules called Dragon Lab where they can do individual investigations. We've talked to Orbital about potentially using their cargo vehicle as a temporary space station in low-Earth orbit. So I think when we think about the private sector taking over, we don't need to think about this big massive investment of a space station. They can learn what research really benefits them. If it's in the pharmaceutical area, if it's in materials processing, if it's in protein crystal growth, they can build a unique capability to do that. It can be much smaller.

So I think the private sector has the capability and can do that on their own, and again, I think NASA's role is to kind of move that human presence further. And we want to go into the region around the moon so there may be a habitation capability again supplied potentially by the private sector for cargo in the vicinity of the moon. But I think NASA's next focus is some kind of habitation capability potentially in the vicinity of the moon.

Mr. BRIDENSTINE. Roger that. I yield back.

Chairman BABIN. Thank you. And now I'd like to recognize the gentleman from Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. Thanks, Mr. Chairman, and thank you to the panelists. Mr. Administrator, it's good to see you. Some days you're here after we've had successes. Some days you're here after we've had some disappointments but appreciate the fact that we just keep moving forward. And it's not easy. You know, this is a risky business that you all are in, and we recognize that. And we don't want to have many disappointments. We want to have mostly successes.

And I became more comfortable in understanding the kind of oversight that goes with the contractor-led investigation process, that in fact you are very involved and that there has to be some kind of sign-off as part of all of this because, oftentimes we have everybody looking over everybody else's shoulder. This seems to be a pretty sensible way to approach it, and I appreciate that.

My questions are generally for you, Dr. Pawelczyk, and for you, Ms. Oakley, just really on what our research is doing on the Space Station that will help us as we move forward to sending our astronauts to Mars and for you so we have the researcher and the futur-

ist, if you will, sitting next to the one who has to figure out how do you pay for it and what's the return.

So I'd like to have you answer. Just generally, how do you see the Space Station advancing our goal of going to Mars? And I'd like to ask you, Ms. Oakley, what do you see in terms of the cost and the benefits from an accountant's point of view? So I'll just turn it over to you two.

Dr. PAWELCZYK. To make sure that Ms. Oakley has time, I'll be brief. There are really three issues that we're dealing with here. They are the biological changes that we see in this continuous reduced gravity environment. Bone and muscle are some of the largest. It is this very energetic radiation environment that we understand to a large extent from the standpoint of solid tumors, but when we start to look at interactions of things like effects in the brain, accelerated cardiovascular disease——

Mr. PERLMUTTER. Is this part of why you have one Kelly on the Space Station and one Kelly on the ground?

Dr. PAWELCZYK. It is. It's an absolutely unique experiment because genetically they're identical. And so the changes in space give you a chance to really talk about what's the variation that's exclusively because of the space environment.

And then of course there are the behavioral issues. You know, we're moving in that futuristic role. Right now the ISS really works in concert with the ground. When we begin to go to inter-planetary operations, those crew members are going to be working quite autonomously from the ground. It's just a matter of distance. And so how people function, independent of this planet, will be very different than how we operate on the ISS today.

Mr. PERLMUTTER. Thank you.

Ms. OAKLEY. The bottom line is NASA does need a robust science program on the International Space Station to be able to achieve those longer-term exploration goals. However, NASA has to be able to pay for it, and the Congress has to be able to pay for it. And that relies on a robust commercial participation in low-Earth orbit to be able to do some of the things that NASA needs to divert funding for the longer term exploration goals, too. Like Mr. Gerstenmaier was referring to, being able to establish those markets in low-Earth orbit to do some of the research that's going to be required to support those long-duration human exploration flights is going to be essential, and getting them to pay for it is also going to be essential because going to Mars is expensive.

Mr. PERLMUTTER. So are you comfortable with the accounting and the auditing that's gone on to date on this program? I mean, the numbers?

Ms. OAKLEY. On the International Space Station program? I haven't looked specifically at the accounting associated with that. What I will say is that I haven't seen any cost estimates associated with extending the International Space Station program beyond 2020, and I think that that's going to be key for the understanding of approving the funding and for everybody getting a very good understanding of what it's going to take to do the extension, to do the science that's required and to do it safely.

Mr. PERLMUTTER. Okay. Thank you. Just one more question, and to Mr. Martin, we've had some incidents now where there have

been some failures. We had some schools in Colorado that had experiments on both the Orbital launch and also most recently on the SpaceX, same school. They did it twice, and they lost both.

How do we account for the cargo that's lost? Is there any compensation to those people or those schools or whatever?

Mr. MARTIN. There is not. I think CASIS on the two flights of SpaceX and the Orbital failures lost over $650,000 of CASIS-funded experiments on those flights. The poor school children in your district lost two sets; NASA, as Mr. Gerstenmaier indicated, over $100 million, that's gone. The taxpayers are paying for that.

Mr. PERLMUTTER. Okay. Well, I thank you for your testimony. Thank you all for being here today, and I yield back.

Chairman BABIN. Thank you, sir. And now I'd like to recognize the gentleman from California, Mr. Knight.

Mr. KNIGHT. Thank you, Mr. Chair. Just a couple of questions. Mr. Gerstenmaier, as a police officer who does investigations on accidents, we have seen a big change in our accident investigation over the last 50 years. I would expect to have seen a big change in investigations over space problems over the last 60 years.

It hasn't been easy going to space in the 1960s. It isn't easy today. Can you give me an idea of how investigations go today and how we can either move through the process, making sure that we're going through and hitting the points and making sure that we're becoming safer as we move through the investigation, but also making sure we can go quicker because the faster we can move, the faster we can do more of this.

Mr. GERSTENMAIER. Kind of our underpinning is first of all we need to be careful we don't jump to conclusions or assume that we know what the failure is to begin with. So we do a very methodical process of where we gather all the data. We need to make sure the time synchronization of that data is all critical, and that's not easy. You know, these events occur in milliseconds. So if you have a camera that's running and the time is on that, you have to make sure that the time on that camera is identical to the telemetry that's coming from the spacecraft. You know, is the timing of when the event occurred recorded on the spacecraft versus recorded after it's received on the ground? So that radio delay time to get down is important.

So the first thing is to gather the data, get it all time synchronous. Then you can start through the methodical process of building what we call a fault tree. So we essentially brainstorm. There are now electronic tools available that automatically build a fault tree for us. They ask inquisitive questions. You lay out all the potential failures that could occur, that could have contributed to the event, which ones have to occur maybe with another event. Then your team meticulously goes through and then crosses off each one of those events as they move forward.

In terms of speed, what we're seeing here in the case of SpaceX is because they're a very much vertically integrated company. They do almost all of their work in-house. They immediately went to testing certain components. So even though they showed up on the fault tree, they said why don't we just go ahead and build up a test rig right now and we'll be prepared to go test.

So even these short number of days between the event and now they're off, actually off in the laboratory doing some stress tests on some components that may contribute kind of as a parallel activity to this more methodical process I laid out.

So I think the advantage and the speed piece is we can use tools. We can use analysis. We have software, and then we can do physical tests in a much faster time than we did before.

Mr. KNIGHT. No, and I agree. I talked to SpaceX several times since the incident, and Virgin and The Spaceship Company, after Spaceship II went down. And they were. They were jumping on it quickly, and they were learning things very fast. And it seems to me that the investigation process, and now with private companies being in fault, it seems like it is going a little bit faster. And that is a good thing. We want to make it safer. I know everyone wants to make it as safe as they possibly can, and that's the truth. Spaceflight still is in its infancy, and we're still learning and we will be for hundreds of years yet. And the faster we can get through some of these investigations, the faster we can move and progress.

Doctor, I just had one question for you because I think that there was some good conversation there that we've got an astronaut working today, and we've got one on the ground. And I think that we'll get some good information there on what the effects are on the body when we actually send people to Mars on such a long, prolonged spaceflight.

Can you give us an idea of what we're going to look at in the next 35 years, or maybe shorter as Administrator Bolden thinks, of when we are going to go to Mars and the effects on the body, not just the radiation but the time in space?

Dr. PAWELCZYK. So Mr. Knight, I apologize. I forgot my crystal ball this morning. But I'll do the best I can.

Mr. KNIGHT. You're a kinesiologist. You should know this.

Dr. PAWELCZYK. So we have mentioned, you know, a couple of those risks that we're seeing in the radiation realm. What's been really interesting to look at, if I talked to you ten years ago I would have told you that I expected to see about 50 percent bone loss from a human being. We thought that that's essentially what gravity confers.

We've seen with some of the implementation strategies for countermeasures on the ISS, that we're looking probably a lot better than that. I'm not willing to say that we have bone completely mitigated at this point. But some of the loading strategies are considerably better.

We've also seen some newly-emergent risks, and that's always the problem. One particular with vision of astronauts. And that is actively being worked on by NASA. So there's been a number of ground-based research protocols. So this is a great example of how NASA quickly identified a problem, immediately engaged the scientific community to try to effect solutions.

Mr. KNIGHT. Very good. Thank you, Mr. Chair. I yield back.

Chairman BABIN. Yes, sir. I'd like to recognize the gentleman from Ohio, Mr. Johnson.

Mr. JOHNSON OF OHIO. Well, thank you, folks, and I'm a big fan of space exploration. I'm a big Buck Rogers fan, Star Trek, all of

those kinds of things, growing up with them as a kid. I say that jokingly, but I can tell you that sitting in my living room floor between the summer of my ninth- and tenth-grade year and watching Neil Armstrong and Buzz Aldrin land on the moon, it captivated me as it did the rest of the world, and I've never gotten over that. So I have tremendous respect for what you folks do and the discoveries that we're making through our space exploration process.

Mr. Gerstenmaier, just one question for you to start off with. The ISS has not yet been extended by Congress. However, the administration has proposed to extend to 2024. How many of our international partners have agreed to extension? And what steps is NASA taking to build a coalition of our international partners for an extension?

Mr. GERSTENMAIER. The Canadian Space Agency has agreed to extend to 2024. So we have one partner on board, that's the Canadian Space Agency, who does a lot of our robotic activities and have the robotic equipment aboard Station. As I described earlier, the Russians, potentially by the end of this year, could be on board with the extension to 2024. The Japanese are also actively looking at Station extension. They could do that again probably by the end of this year, possibly by the start of their next fiscal year which is in April of 2016, and the Japanese are actively working on that and we're working with them.

Mr. JOHNSON OF OHIO. All right.

Mr. GERSTENMAIER. And the European Space Agency, they're again working through their overall budget process. They've committed to support us on the Orion capsule as you know. The teams in Ohio are working with them on the European Service Module that sits underneath the Orion capsule. They're pretty much committed. They're not committed to Station yet. They will do probably that in 2017 formally, but they're doing all the activities of getting with all the member states and all the member countries to approve, and they see again tremendous benefit. It's just working through their big governmental process on the ESA side. So I think all partners are heading towards Station extension to 2024 in a varying timeframe.

Mr. JOHNSON OF OHIO. A quick follow-up. How significant of a partner are the Russians? I mean, we're pretty dependent upon the Russians right now in terms of getting there and back, correct?

Mr. GERSTENMAIER. Yes. We're dependent upon them for crew transportation. We also use them for altitude adjustments of Space Station. They provide the propellant that reboosts Station. They're dependent upon us for solar as ray or power generation. They also use us for commands and other activities. So we're kind of mutually dependent back and forth between both.

Mr. JOHNSON OF OHIO. Are you having any discussions—I'm sure you've heard the testimony of the potential incoming new Chairman of the Joint Chiefs who has stated that the Russians are our biggest security risk, security threat? I mean, we're kind of in a dichotomy with the Russians here. You guys concerned about that? And what's your back-up plan?

Mr. GERSTENMAIER. Again, I would say, first of all, from a civil space standpoint, as I described earlier we have a very strong relationship with the Russians and will continue to do that. I think we

need to again look at what happens if the Russians pull out in certain key areas. As we're working hard on the Commercial Crew Program, we want to end our sole reliance on the crew transportation system as soon as we can, and funding for that is absolutely critical to get it in place so we can have a U.S. capability to augment the Russians in the December 2017 or so timeframe.

So I think we're moving out on crew transportation. The other areas that I described where we're dependent, we have workarounds and we can put systems in place to recoup that if we have to. But at the end, I think it's advantageous to us if we can cooperate. There's real advantages to us. That's the right way to go forward. These endeavors require of us all to work together, but we also need to be not so naive that if a problem occurs, that we can't continue on without a certain partner.

Mr. JOHNSON OF OHIO. Okay. All right. Well, you know, I guess, you know, we've had some failures with the commercial avenue. And I'm sure that you are, but I hope there's a lot of discussion going on because if we continue to experience similar failures like we had with the Commercial Cargo Program and the Russians were to back out, our options become smaller and fewer. Okay, Mr. Chairman. I yield back.

Chairman BABIN. Thank you. Now I'd like to recognize the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman. And I remember when the Space Station was first approved. It only won by one vote in this Committee, one vote. Boy, I'm glad I voted for it. Don't disappoint me. Don't disappoint me now.

Does anyone here know the level of CO_2 that is in the atmosphere of the Space Station? You have an internal atmosphere. What element do we put CO_2 in? There's a lot of talk about CO_2 in the planet now. What does CO_2 do in the Space Station?

Mr. GERSTENMAIER. I believe we've been holding it low because of the potential eye problems. I think we're running about three millimeters of mercury of partial pressure of CO_2 on board Station.

Mr. ROHRABACHER. How does that compare to the CO_2 that we have in our atmosphere here?

Mr. GERSTENMAIER. It's higher than the atmosphere we have in the room here, and we've typically allowed, prior to the intracranial pressure problems associated with the vision, we allowed it to go up on the order of six or so millimeters per mercury, and that's dramatically higher than the environment here. So it's higher CO_2 levels on board Station than we see here.

Mr. ROHRABACHER. Have there been any health-related problems, this increased level of CO_2 that astronauts breathe in during their time at the Space Station as compared to what they would breathe in here?

Mr. GERSTENMAIER. Yes, we're not sure but we think it could contribute to the intracranial pressure problem which causes the eye and vision problem we described. At higher elevated levels of CO_2 you can get headaches. You can have some other physiological problems. And again, we try to control that as low as we can. We have a Russian device that removes carbon dioxide. We have a U.S. device that removes carbon dioxide. Then we also have some absorbent material that also removes it. And then we have a next

generation of system that will fly on the Orion capsule that's also on board Station, and we can use that also to remove CO_2.

Mr. ROHRABACHER. Because we are actually exhaling CO_2 all the time, right? So we have to be—if you're in an enclosed environment, be very concerned with what the human body itself is exhaling.

In terms of the future of Space Station, do we have plans to expand, put different elements onto the Space Station at this point?

Mr. GERSTENMAIER. Currently on the U.S. side, we just reconfigured the permanent multi-purpose module from one location to another location. That was to make room for a docking adaptor that we discussed earlier to let commercial vehicles come. That's about all we're going to do on the U.S. side. There's no major new additions coming. The Russians have talked about a solar power platform to provide some solar energy for their segment. The Russians have also talked about a multi-purpose logistics module, another research module that they may add to Station.

Mr. ROHRABACHER. Does the——

Mr. GERSTENMAIER. So the Russians may add some additional modules, but we on the U.S. side don't have any major additions planned.

Mr. ROHRABACHER. The Bigelow Company has actually invested a considerable amount of money in developing a new concept for space habitat, the inflatables. Is there any use of this technology?

Mr. GERSTENMAIER. Yes, it'll be added to Space Station next year. It's a demonstration capability. This is an expandable module that will be added to the outside of Station. It will stay there for about a year or year-and-a-half, and then we'll remove it from Station. Its purpose is to investigate the advantages of an expandable module. So instead of a rigid pressure shell, it's to understand what we can gain from the expandable technology. It has some very thick walls, so it may be better from a micro-meteoroid to penetration standpoint. It also may be better thermally. That needs to be looked at. And the acoustic environment may be better.

So the idea is to get it on orbit, actually take those claims, test them on orbit with Space Station, use the unique capabilities of Station, confirm if that module technology is something we want to use going forward.

Mr. ROHRABACHER. And it might also be cheaper than the traditional way of building a space station which is something we should be concerned about.

Let me just note two things, one is that orbital debris continues to be and always was and is an expanding concern. I believe that this is something NASA should look at, not just in terms of Space Station, but we should be thinking about international cooperative effort to just deal with the debris problem. That's something we need to, this Committee should be dealing with at least in the time ahead.

And second and last of all, let me just note that your report on your cooperation with Russia during this time period when there are, how do you say, frictions going on between the United States and Russia, I think demonstrates a very wonderful aspect of space and that is once you get up there, you look back down on the Earth and some of those problems don't seem as important or we're able

to put it in perspective, and I'm happy to hear that we are and that the Russians are putting these areas of friction in perspective to the point that we can work together and create a better world while we're doing it. So thank you very much for demonstrating that to all of us.

Chairman BABIN. Thank you. We have just had votes called, and I want to thank the witnesses for their valuable testimony and the members for all their questions. I'd really, if we would have had time, I would have liked to have gone through with a second round, but the record will remain open for two weeks for additional comments and for written questions from members. And it's our hope that the Office of Management and Budget will work more expeditiously with NASA to put together responses to these questions.

The Committee is still waiting for NASA's responses to questions for the Commercial Crew hearing from six months ago. Mr. Gerstenmaier, please send back the message that these delays are not acceptable.

The witnesses are excused, and this hearing is adjourned. Thank you.

[Whereupon, at 10:45 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Bill Gerstenmaier

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"The International Space Station: Addressing Operational Challenges"

Questions for the record, Mr. Bill Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA

Questions submitted by Rep. Jim Bridenstine, Member, Subcommittee on Space

Question 1:

If the United States is faced with a scenario in which a backup launch system is immediately needed, and Russia is not a reliable partner, are there other international launch entities we could rely on?

Answer 1:

While NASA anticipates that U.S. commercial crew vehicles will begin flying in 2017, until a U.S. commercial vehicle is operationally available, the Russian Soyuz is the only crew transportation and rescue vehicle available for continued access to crew launch, return and rescue services.

Question 1a:

What has been the performance history of these other launch entities?

Answer 1a:

Please see response to Question #1, above.

Question 2:

Your testimony indicated that NASA does not currently have plans to maintain a U.S. government presence in LEO following the end of the ISS program.

a. Can you provide this Committee with the U.S. code, statements of administration policy, or any other relevant documents that have informed this decision?

Answer 2a:

The U.S. Government will continue to maintain assets in low-Earth orbit (LEO), but in terms of crewed spaceflight, NASA has been focused on going beyond LEO. In this "Journey to Mars" strategy, NASA will use the unique environment of International Space Station (ISS) to conduct the research and technology demonstrations necessary to keep our crews safe and productive on

long-duration spaceflights. We will then travel beyond low-Earth orbit (LEO) to the proving ground of cis-lunar space. These steps will build the foundation for further deep-space exploration. With the technologies and techniques we develop, we will enable expeditions to multiple destinations, ultimately allowing us to pioneer Mars and other destinations as we lay the groundwork for permanent human settlements in the solar system. Currently, NASA, along with the Center for the Advancement of Science In Space (CASIS), is focused on enabling LEO commercial markets through the ISS National Laboratory. It is NASA's intention that by the time the ISS is retired, that commercial companies will have established enterprises that will be able to sustain platforms and capabilities in LEO from both the demand and supply sides.

Conducting beyond-LEO human space exploration is one of the key priorities of the Agency and of the NASA Authorization Act of 2010. The more commercial enterprises can accomplish in LEO, the more NASA can accomplish in deep space exploration.

Question 2b:

How has this decision been communicated to our international partners?

Answer 2b:

NASA discusses our plans for human space flight with our International Partners in the International Space Station (ISS) program, in the International Space Exploration Coordination Group (ISECG), and with the broader international space exploration community in other bilateral and multilateral fora. We have shared our plan to build on the strong foundation that is the ISS, undertaking missions of increasing distance and complexity in the proving ground of cis-lunar and cis-Mars space as we prepare for the human Journey to Mars.

NASA's exploration strategy is consistent with the Global Exploration Roadmap (GER), released in August 2013, with 11 of NASA's international space agency partners in the ISECG. The roadmap begins with the ISS and includes a step-wise expansion of human presence into the solar system, with human missions to the surface of Mars as a driving goal. The space agencies in the ISECG are continuing to further elaborate a common vision for the future of low-Earth orbit, maximizing the use of the orbiting laboratory during its lifetime while ensuring a research platform remains in low-Earth orbit for government and non-government use.

Question 2c:

How has this decision been communicated to the Commercial Resupply and Commercial Crew contractors?

Answer 2c:

NASA's "Journey to Mars" strategy, as well as its support of the development of a LEO space economy that would go beyond the Agency's requirements, has been a matter of public record. In addition, NASA's vision was communicated at a LEO Commercialization workshop held in December of 2014 with broad participation from commercial stakeholders. NASA has presented

these plans at Federal Aviation Administration (FAA) Commercial Space Transportation Advisory Committee (COMSTAC) meetings, which are attended by numerous commercial companies.

Question 3:

Do you believe this is the appropriate decision, or should NASA maintain a post-ISS presence in LEO, whether as an operator or a customer?

Answer 3:

It is important to expand human presence into the solar system and to Mars, consistent with Presidential and Congressional direction. ISS operations in LEO constitute a foundation for such expansion, but once key research and technology development efforts have been completed, NASA plans to begin operating at greater distances from Earth, establishing a habitation capability in cis-lunar space, for example. NASA needs to expand knowledge and frontiers by pursuing activities which are not ready for commercial or non-Governmental investment. NASA has worked to encourage the development of a LEO space economy that will be sustainable beyond the operational lifetime of ISS. While the Agency doesn't anticipate requiring commercial human spaceflight services in LEO beyond Station, should such requirements arise in the future, NASA would consider whether available commercial services could be used to meet those needs.

Question 4:

Can you provide this Committee with a detailed plan entailing what maintaining a presence in LEO would require, in order to give Congress the necessary information to craft such a policy in future NASA authorization legislation?

Answer 4:

NASA's efforts for crewed missions in the post-ISS environment are focused on developing the Orion crew vehicle and Space Launch System (SLS) heavy-lift launcher for deep-space missions of exploration. The Agency plans to fly missions in cis-lunar space by the end of the 2020s using a habitation capability. Like Station before them, these vehicles will pave the way for a crewed Mars mission.

It is NASA's intention to transition LEO to private platforms and capabilities enabled by commercial markets and Government agencies with interest in LEO research and activities, while NASA's focus shifts toward deep space beyond LEO. NASA and CASIS are working to encourage the growth of a LEO space economy that will continue to develop even after the end of the International Space Station's (ISS) lifetime. Private enterprise and affordable commercial operations in LEO will enable a truly sustainable step in our expansion into space — a robust, vibrant, commercial enterprise with many providers and a wide range of private and public users will enable U.S. industry to support other Government and commercial users safely, reliably, and at a lower cost.

Question 4a:

Please delineate the role of U.S. industry developed habitats in any such plan.

Answer 4a:

Please see response to Question #4, above.

Question 5:

Does NASA have plans to carry out a commercial habitat development program?

Answer 5:

NASA's journey to deep space will include key partnerships with commercial industry for the development of advanced exploration systems. In an effort to stimulate deep space capability development across the aerospace industry, NASA released the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) and selected 12 projects to advance the development of necessary exploration capabilities. Through these public-private partnerships, NextSTEP partners will provide advance concept studies and technology development projects in the areas including habitation systems. Four of the awards will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS). In addition to advancing capabilities for NASA required for beyond-Earth-orbit habitation, the advances made through this effort by the selected commercial companies may be applicable to any private space stations/habitats.

In addition to the NextSTEP program, a two-year demonstration of habitation technology will occur when Bigelow Aerospace's Bigelow Expandable Activity Module (BEAM) is flown to ISS on a SpaceX Dragon spacecraft in the coming months. Astronauts will use the Station's robotic arm to install the module on the aft port of the Tranquility node, then activate a pressurization system to expand the BEAM structure to its full size using air stored within the packed module. During the two-year test period, station crew members and ground-based engineers will gather performance data on the module. While the BEAM demonstration supports a NASA objective to develop a deep space habitat for human missions beyond Earth orbit, the results of the demonstration will also have applications to private space stations/habitats, which is why Bigelow has co-funded the development of this module.

As discussed in the response to Question #2, above, NASA has been developing a strategic plan for enabling a commercial presence in LEO beyond the ISS, which could include commercial platforms and other support capabilities, such as communications. By way of informing this strategy, NASA issued a Request for Information in the Spring of 2014, followed by a workshop with industry in December 2014. NASA is also working with industry partners through the NextSTEP BAA across multiple disciplines to help inform the path forward in LEO and in cis-lunar space. Feedback from those initiatives indicates that industry is interested in commercial platforms and other capabilities or services. NASA's strategy is that commercial industry will be able to leverage the development of future long-duration, deep-space habitation systems for NASA for their own commercial LEO platforms.

Question 5a:

Can you please provide detailed information on how you envision such a program to unfold, including any similarities or differences to the cargo and crew programs, particularly as it pertains to funding and contracting mechanisms; certification processes; and government tenancy?

Answer 5a:

NASA does not currently have plans to develop another Earth-orbiting space station. With regard to other future efforts related to space habitation, NASA is committed to determining the most appropriate procurement mechanism that stimulates maximum competition for future space vehicles. Such determination will be dependent on a number of factors and will be consistent with Federal laws and regulations as well as Agency guidance.

Question 6:

There are currently only two launches of SLS planned, with a flight rate of one every 3 to 4 years. This low flight rate of the SLS is a big concern of mine. Can you outline options and potential missions to increase the flight rate of SLS?

Answer 6:

SLS is being designed to be capable of supporting a long-term flight rate of one per year with a surge capability of three per year. The actual cadence of missions beyond 2022 will be defined in the coming months and years based on mission needs, available resources, and operational costs, which will be better known once development is complete.

Question 6a:

Do you see a second unmanned flight of SLS, carrying a certified payload and launching between EM-1 and EM-2, as a viable option?

Answer 6a:

The three Exploration Systems Development programs: the Orion crew vehicle, SLS, and Exploration Ground Systems, are resourced to support Exploration Missions-1 and 2 (EM-1 and EM-2). When tasks related to EM-1 are completed on any of the three programs, the workforce can progress to EM-2. NASA does not see a second flight of SLS, inserted between EM-1 and EM-2, as a viable option under current funding and hardware manufacturing plans.

Question 7:

What mission duration is envisioned for future cis-lunar and beyond-cis-lunar missions and how many crewmembers does NASA plan to fly on these missions?

Answer 7:

Crewed missions in the proving ground of cis-lunar space are envisioned to last from 1-12 months, while an "Earth independent" mission (e.g., to Mars or its moons) would last 2-3 years. The crew complement for different missions will vary. The Orion crew exploration vehicle is capable of supporting four crewmembers for 21 days without any additional module. NASA's Asteroid Redirect Mission (ARM) would send an Orion with a crew of two to rendezvous with a captured asteroid boulder in lunar distant retrograde orbit for 24-25 days. For missions that require longer durations than can be supported by Orion alone, the Agency would use habitation capabilities yet to be developed. NASA plans to fly these longer-duration missions by the end of the 2020s to validate the habitation capabilities required for Mars-class missions.

Question 7a:

How much pressurized volume will NASA need to successfully carry out these missions and be in compliance with parameters set forth in the Human Integration Design Handbook?

Answer 7a:

Concepts for cis-lunar and other deep-space habitation and transit capabilities are not yet fully defined. The parameters in the referenced handbook imply that for a crew of four on 1,000-day Mars-class missions, 100 m^3 habitable volume is required for the crew habitation and approximately 100 m^3 habitable volume is required for logistics and spares.

Question 7b:

Will exploration habitats be necessary to accommodate these missions?

Answer 7b:

Please see response to Question #7, above.

Question 7b-i:

Does NASA plan on utilizing commercially-built habitats?

Answer 7b-i:

NASA is committed to determining the most appropriate procurement mechanism that stimulates maximum competition for future missions. Such determinations will be dependent on a number of factors and will be consistent with Federal laws and regulations as well as business case analysis.

Question 7c:

Would a launch of an exploration habitat prior to the first crewed mission of the SLS be

beneficial for testing the viability of exploration habitats for future cis- lunar and beyond-cis-lunar missions?

Answer 7c:

The ISS serves as an excellent testbed for future exploration technologies to be used on cis-lunar and beyond-cis-lunar missions, including habitation capability. NASA is not currently considering a second flight of SLS prior to a crewed EM-2.

Question 8:

In the FY2015 Omnibus, NASA received an approximately $30M increase for its Advanced Exploration Systems (AES) program, accompanied by report language to focus on habitat structure development. Further, both House and Senate NASA appropriations contained increases for the AES program, again with language prioritizing habitat development.

a. Can you provide a detailed account of how NASA has utilized the FY 2015 AES funds to comply with Congressional intent?

Answer 8a:

Please see response to Question #5, above, regarding the habitation systems component of NASA's NextSTEP effort, as well as the pending flight of the BEAM module to the ISS for testing. NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS):

- Lockheed Martin - Denver, CO: Habitat to augment Orion's capabilities. Design will draw strongly on LM and partner Thales Alenia's heritage designs in habitation and propulsion;
- Bigelow Aerospace LLC - Las Vegas, NV: The B330 for deep-space habitation will support operations/missions in LEO, distant retrograde orbit, and beyond cis-lunar space;
- Orbital ATK - Dulles, VA: Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cis-lunar and long duration deep space transit habitation capabilities and technologies;
- Boeing - Houston, TX: Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cis-lunar and Mars exploration;
- Dynetics, Inc - Huntsville, AL: Miniature atmospheric scrubbing system for long-duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air;
- Hamilton Sundstrand Space Systems International - Windsor Locks, CT: Larger, more modular ECLSS subsystems, requiring less integration and maximize component commonality; and

- Orbitec - Madison, WI: Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems.

Question 8b:

Can you provide a detailed plan for how NASA plans to utilize any future funding increases for AES to carry out the next steps of habitat development?

Answer 8b:

The President's FY 2016 Budget Request supports the next phase of the NextSTEP effort, in which NASA will proceed to enter into fixed price contracts with technical/payment milestones with private-sector partners. Multiple awards are made for concept studies and technology development in several areas, including habitation. Studies can address transportation, operations, or environmental capabilities of a habitation system. The emphasis for eligibility and execution is placed on technical ability to mature technologies and commitment to application, as well as the contribution of private corporate resources to the private-public partnership to achieve goals and objectives.

Question 9:

The United States Commercial Remote Sensing Policy directs the federal government "to advance and protect U.S. national security and foreign policy interests by maintaining the nation's leadership in remote sensing space activities, and by sustaining and enhancing the U.S. remote sensing industry. Doing so will also foster economic growth, contribute to environmental stewardship, and enable scientific and technological excellence. In support of this goal, the United States Government will enable U.S. industry to compete successfully as a provider of remote sensing space capabilities for foreign governments and foreign commercial users, while ensuring appropriate measures are implemented to protect national security and foreign policy." UrtheCast is a Canadian company that operates remote sensing instruments aboard the Russian segment of the ISS. These instruments benefit from access to the U.S. Tracking and Data Relay Satellite System (TDRSS) for communications data links via their partnership with NanoRacks LLC, which holds a Space Act Agreement with NASA. Several U.S. companies (including, but not limited to DigitalGlobe, PlanetLabs, and Skybox Imaging) have developed remote sensing capabilities and are offering commercial products. Does NASA view this as subsidizing the operations of foreign competitors?
Answer 9:

The UrtheCast cameras on the ISS are part of an international project involving several nations. By providing access to its cameras online, UrtheCast is contributing significantly to engaging the public in NASA's mission and increasing interest in space. UrtheCast's use of the Tracking and Data Relay Satellite System (TDRSS) through its partner, Nanoracks (a U.S. company) does not impact NASA's mission needs and will improve connectivity for citizen scientists and others who seek to access the UrtheCast imagery. To the extent compatible with NASA's mission needs, NASA will continue to support its partners, such as Nanoracks, and welcome additional opportunities to support commercial use of the ISS.

Question 9a:

Does NASA have a policy or process for reviewing or updating Space Act Agreements to ensure that they are complaint with U.S. laws, regulations, and policies? If so, please provide this policy or an explanation of the process.

Answer 9a:

NASA ensures that appropriate terms and conditions are included in each Space Act Agreement (SAA) at the outset, with updates as required by changes in the law. NASA Policy Directive (NPD) 1050.1 (please see link below) establishes responsibilities for negotiation, execution, amendment, and termination of SAAs. Per Section 5e, the NASA General Counsel (for Headquarters Agreements) or the Center Chief Counsel (for Center Agreements) is responsible for reviewing all Agreements entered into under this NPD to ensure compliance with applicable statutes, regulations, and policies.

http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_1050_001I_&page_name=main

Question 9b:

Has NASA taken any formal measures or analyses to determine if this arrangement could negatively impact the U.S. commercial remote sensing industry?

Answer 9b:

Via its Space Act Agreement with NanoRacks, NASA is supportive of a broader utilization of the ISS by non-traditional users. As such, it was expected that U.S. commercial firms may engage in partnerships with other-than-U.S. firms, just as is common in virtually any industry. It was not felt that this partnership with Urthecast presented any special challenges, nor did it circumvent the intent of the U.S. Commercial Remote Sensing Policy. The potential partnership between NanoRacks and Urthecast was carefully considered and deemed worthy of support, given the terms of the SAA with NanoRacks and the understanding that use of U.S. communication assets would be on a non-interference basis. Teledyne Brown, a U.S. company, is also testing Earth-imaging and hyperspectral measurement from ISS. This work is supported by a cooperative agreement.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"The International Space Station: Addressing Operational Challenges"

Questions for the record, Mr. Bill Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA

Questions submitted by Rep. Jim Bridenstine, Member, Subcommittee on Space

Question 1:

If the United States is faced with a scenario in which a backup launch system is immediately needed, and Russia is not a reliable partner, are there other international launch entities we could rely on?

Answer 1:

While NASA anticipates that U.S. commercial crew vehicles will begin flying in 2017, until a U.S. commercial vehicle is operationally available, the Russian Soyuz is the only crew transportation and rescue vehicle available for continued access to crew launch, return and rescue services.

Question 1a:

What has been the performance history of these other launch entities?

Answer 1a:

Please see response to Question #1, above.

Question 2:

Your testimony indicated that NASA does not currently have plans to maintain a U.S. government presence in LEO following the end of the ISS program.

a. Can you provide this Committee with the U.S. code, statements of administration policy, or any other relevant documents that have informed this decision?

Answer 2a:

The U.S. Government will continue to maintain assets in low-Earth orbit (LEO), but in terms of crewed spaceflight, NASA has been focused on going beyond LEO. In this "Journey to Mars" strategy, NASA will use the unique environment of International Space Station (ISS) to conduct the research and technology demonstrations necessary to keep our crews safe and productive on

long-duration spaceflights. We will then travel beyond low-Earth orbit (LEO) to the proving ground of cis-lunar space. These steps will build the foundation for further deep-space exploration. With the technologies and techniques we develop, we will enable expeditions to multiple destinations, ultimately allowing us to pioneer Mars and other destinations as we lay the groundwork for permanent human settlements in the solar system. Currently, NASA, along with the Center for the Advancement of Science In Space (CASIS), is focused on enabling LEO commercial markets through the ISS National Laboratory. It is NASA's intention that by the time the ISS is retired, that commercial companies will have established enterprises that will be able to sustain platforms and capabilities in LEO from both the demand and supply sides.

Conducting beyond-LEO human space exploration is one of the key priorities of the Agency and of the NASA Authorization Act of 2010. The more commercial enterprises can accomplish in LEO, the more NASA can accomplish in deep space exploration.

Question 2b:

How has this decision been communicated to our international partners?

Answer 2b:

NASA discusses our plans for human space flight with our International Partners in the International Space Station (ISS) program, in the International Space Exploration Coordination Group (ISECG), and with the broader international space exploration community in other bilateral and multilateral fora. We have shared our plan to build on the strong foundation that is the ISS, undertaking missions of increasing distance and complexity in the proving ground of cis-lunar and cis-Mars space as we prepare for the human Journey to Mars.

NASA's exploration strategy is consistent with the Global Exploration Roadmap (GER), released in August 2013, with 11 of NASA's international space agency partners in the ISECG. The roadmap begins with the ISS and includes a step-wise expansion of human presence into the solar system, with human missions to the surface of Mars as a driving goal. The space agencies in the ISECG are continuing to further elaborate a common vision for the future of low-Earth orbit, maximizing the use of the orbiting laboratory during its lifetime while ensuring a research platform remains in low-Earth orbit for government and non-government use.

Question 2c:

How has this decision been communicated to the Commercial Resupply and Commercial Crew contractors?

Answer 2c:

NASA's "Journey to Mars" strategy, as well as its support of the development of a LEO space economy that would go beyond the Agency's requirements, has been a matter of public record. In addition, NASA's vision was communicated at a LEO Commercialization workshop held in December of 2014 with broad participation from commercial stakeholders. NASA has presented

these plans at Federal Aviation Administration (FAA) Commercial Space Transportation Advisory Committee (COMSTAC) meetings, which are attended by numerous commercial companies.

Question 3:

Do you believe this is the appropriate decision, or should NASA maintain a post-ISS presence in LEO, whether as an operator or a customer?

Answer 3:

It is important to expand human presence into the solar system and to Mars, consistent with Presidential and Congressional direction. ISS operations in LEO constitute a foundation for such expansion, but once key research and technology development efforts have been completed, NASA plans to begin operating at greater distances from Earth, establishing a habitation capability in cis-lunar space, for example. NASA needs to expand knowledge and frontiers by pursuing activities which are not ready for commercial or non-Governmental investment. NASA has worked to encourage the development of a LEO space economy that will be sustainable beyond the operational lifetime of ISS. While the Agency doesn't anticipate requiring commercial human spaceflight services in LEO beyond Station, should such requirements arise in the future, NASA would consider whether available commercial services could be used to meet those needs.

Question 4:

Can you provide this Committee with a detailed plan entailing what maintaining a presence in LEO would require, in order to give Congress the necessary information to craft such a policy in future NASA authorization legislation?

Answer 4:

NASA's efforts for crewed missions in the post-ISS environment are focused on developing the Orion crew vehicle and Space Launch System (SLS) heavy-lift launcher for deep-space missions of exploration. The Agency plans to fly missions in cis-lunar space by the end of the 2020s using a habitation capability. Like Station before them, these vehicles will pave the way for a crewed Mars mission.

It is NASA's intention to transition LEO to private platforms and capabilities enabled by commercial markets and Government agencies with interest in LEO research and activities, while NASA's focus shifts toward deep space beyond LEO. NASA and CASIS are working to encourage the growth of a LEO space economy that will continue to develop even after the end of the International Space Station's (ISS) lifetime. Private enterprise and affordable commercial operations in LEO will enable a truly sustainable step in our expansion into space — a robust, vibrant, commercial enterprise with many providers and a wide range of private and public users will enable U.S. industry to support other Government and commercial users safely, reliably, and at a lower cost.

Question 4a:

Please delineate the role of U.S. industry developed habitats in any such plan.

Answer 4a:

Please see response to Question #4, above.

Question 5:

Does NASA have plans to carry out a commercial habitat development program?

Answer 5:

NASA's journey to deep space will include key partnerships with commercial industry for the development of advanced exploration systems. In an effort to stimulate deep space capability development across the aerospace industry, NASA released the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) and selected 12 projects to advance the development of necessary exploration capabilities. Through these public-private partnerships, NextSTEP partners will provide advance concept studies and technology development projects in the areas including habitation systems. Four of the awards will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS). In addition to advancing capabilities for NASA required for beyond-Earth-orbit habitation, the advances made through this effort by the selected commercial companies may be applicable to any private space stations/habitats.

In addition to the NextSTEP program, a two-year demonstration of habitation technology will occur when Bigelow Aerospace's Bigelow Expandable Activity Module (BEAM) is flown to ISS on a SpaceX Dragon spacecraft in the coming months. Astronauts will use the Station's robotic arm to install the module on the aft port of the Tranquility node, then activate a pressurization system to expand the BEAM structure to its full size using air stored within the packed module. During the two-year test period, station crew members and ground-based engineers will gather performance data on the module. While the BEAM demonstration supports a NASA objective to develop a deep space habitat for human missions beyond Earth orbit, the results of the demonstration will also have applications to private space stations/habitats, which is why Bigelow has co-funded the development of this module.

As discussed in the response to Question #2, above, NASA has been developing a strategic plan for enabling a commercial presence in LEO beyond the ISS, which could include commercial platforms and other support capabilities, such as communications. By way of informing this strategy, NASA issued a Request for Information in the Spring of 2014, followed by a workshop with industry in December 2014. NASA is also working with industry partners through the NextSTEP BAA across multiple disciplines to help inform the path forward in LEO and in cis-lunar space. Feedback from those initiatives indicates that industry is interested in commercial platforms and other capabilities or services. NASA's strategy is that commercial industry will be able to leverage the development of future long-duration, deep-space habitation systems for NASA for their own commercial LEO platforms.

Question 5a:

Can you please provide detailed information on how you envision such a program to unfold, including any similarities or differences to the cargo and crew programs, particularly as it pertains to funding and contracting mechanisms; certification processes; and government tenancy?

Answer 5a:

NASA does not currently have plans to develop another Earth-orbiting space station. With regard to other future efforts related to space habitation, NASA is committed to determining the most appropriate procurement mechanism that stimulates maximum competition for future space vehicles. Such determination will be dependent on a number of factors and will be consistent with Federal laws and regulations as well as Agency guidance.

Question 6:

There are currently only two launches of SLS planned, with a flight rate of one every 3 to 4 years. This low flight rate of the SLS is a big concern of mine. Can you outline options and potential missions to increase the flight rate of SLS?

Answer 6:

SLS is being designed to be capable of supporting a long-term flight rate of one per year with a surge capability of three per year. The actual cadence of missions beyond 2022 will be defined in the coming months and years based on mission needs, available resources, and operational costs, which will be better known once development is complete.

Question 6a:

Do you see a second unmanned flight of SLS, carrying a certified payload and launching between EM-1 and EM-2, as a viable option?

Answer 6a:

The three Exploration Systems Development programs: the Orion crew vehicle, SLS, and Exploration Ground Systems, are resourced to support Exploration Missions-1 and 2 (EM-1 and EM-2). When tasks related to EM-1 are completed on any of the three programs, the workforce can progress to EM-2. NASA does not see a second flight of SLS, inserted between EM-1 and EM-2, as a viable option under current funding and hardware manufacturing plans.

Question 7:

What mission duration is envisioned for future cis-lunar and beyond-cis-lunar missions and how many crewmembers does NASA plan to fly on these missions?

Answer 7:

Crewed missions in the proving ground of cis-lunar space are envisioned to last from 1-12 months, while an "Earth independent" mission (e.g., to Mars or its moons) would last 2-3 years. The crew complement for different missions will vary. The Orion crew exploration vehicle is capable of supporting four crewmembers for 21 days without any additional module. NASA's Asteroid Redirect Mission (ARM) would send an Orion with a crew of two to rendezvous with a captured asteroid boulder in lunar distant retrograde orbit for 24-25 days. For missions that require longer durations than can be supported by Orion alone, the Agency would use habitation capabilities yet to be developed. NASA plans to fly these longer-duration missions by the end of the 2020s to validate the habitation capabilities required for Mars-class missions.

Question 7a:

How much pressurized volume will NASA need to successfully carry out these missions and be in compliance with parameters set forth in the Human Integration Design Handbook?

Answer 7a:

Concepts for cis-lunar and other deep-space habitation and transit capabilities are not yet fully defined. The parameters in the referenced handbook imply that for a crew of four on 1,000-day Mars-class missions, 100 m^3 habitable volume is required for the crew habitation and approximately 100 m^3 habitable volume is required for logistics and spares.

Question 7b:

Will exploration habitats be necessary to accommodate these missions?

Answer 7b:

Please see response to Question #7, above.

Question 7b-i:

Does NASA plan on utilizing commercially-built habitats?

Answer 7b-i:

NASA is committed to determining the most appropriate procurement mechanism that stimulates maximum competition for future missions. Such determinations will be dependent on a number of factors and will be consistent with Federal laws and regulations as well as business case analysis.

Question 7c:

Would a launch of an exploration habitat prior to the first crewed mission of the SLS be

beneficial for testing the viability of exploration habitats for future cis- lunar and beyond-cis-lunar missions?

Answer 7c:

The ISS serves as an excellent testbed for future exploration technologies to be used on cis-lunar and beyond-cis-lunar missions, including habitation capability. NASA is not currently considering a second flight of SLS prior to a crewed EM-2.

Question 8:

In the FY2015 Omnibus, NASA received an approximately $30M increase for its Advanced Exploration Systems (AES) program, accompanied by report language to focus on habitat structure development. Further, both House and Senate NASA appropriations contained increases for the AES program, again with language prioritizing habitat development.

a. Can you provide a detailed account of how NASA has utilized the FY 2015 AES funds to comply with Congressional intent?

Answer 8a:

Please see response to Question #5, above, regarding the habitation systems component of NASA's NextSTEP effort, as well as the pending flight of the BEAM module to the ISS for testing. NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS):

- Lockheed Martin - Denver, CO: Habitat to augment Orion's capabilities. Design will draw strongly on LM and partner Thales Alenia's heritage designs in habitation and propulsion;
- Bigelow Aerospace LLC - Las Vegas, NV: The B330 for deep-space habitation will support operations/missions in LEO, distant retrograde orbit, and beyond cis-lunar space;
- Orbital ATK - Dulles, VA: Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cis-lunar and long duration deep space transit habitation capabilities and technologies;
- Boeing - Houston, TX: Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cis-lunar and Mars exploration;
- Dynetics, Inc - Huntsville, AL: Miniature atmospheric scrubbing system for long-duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air;
- Hamilton Sundstrand Space Systems International - Windsor Locks, CT: Larger, more modular ECLSS subsystems, requiring less integration and maximize component commonality; and

- Orbitec - Madison, WI: Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems.

Question 8b:

Can you provide a detailed plan for how NASA plans to utilize any future funding increases for AES to carry out the next steps of habitat development?

Answer 8b:

The President's FY 2016 Budget Request supports the next phase of the NextSTEP effort, in which NASA will proceed to enter into fixed price contracts with technical/payment milestones with private-sector partners. Multiple awards are made for concept studies and technology development in several areas, including habitation. Studies can address transportation, operations, or environmental capabilities of a habitation system. The emphasis for eligibility and execution is placed on technical ability to mature technologies and commitment to application, as well as the contribution of private corporate resources to the private-public partnership to achieve goals and objectives.

Question 9:

The United States Commercial Remote Sensing Policy directs the federal government "to advance and protect U.S. national security and foreign policy interests by maintaining the nation's leadership in remote sensing space activities, and by sustaining and enhancing the U.S. remote sensing industry. Doing so will also foster economic growth, contribute to environmental stewardship, and enable scientific and technological excellence. In support of this goal, the United States Government will enable U.S. industry to compete successfully as a provider of remote sensing space capabilities for foreign governments and foreign commercial users, while ensuring appropriate measures are implemented to protect national security and foreign policy." UrtheCast is a Canadian company that operates remote sensing instruments aboard the Russian segment of the ISS. These instruments benefit from access to the U.S. Tracking and Data Relay Satellite System (TDRSS) for communications data links via their partnership with NanoRacks LLC, which holds a Space Act Agreement with NASA. Several U.S. companies (including, but not limited to DigitalGlobe, PlanetLabs, and Skybox Imaging) have developed remote sensing capabilities and are offering commercial products. Does NASA view this as subsidizing the operations of foreign competitors?
Answer 9:

The UrtheCast cameras on the ISS are part of an international project involving several nations. By providing access to its cameras online, UrtheCast is contributing significantly to engaging the public in NASA's mission and increasing interest in space. UrtheCast's use of the Tracking and Data Relay Satellite System (TDRSS) through its partner, Nanoracks (a U.S. company) does not impact NASA's mission needs and will improve connectivity for citizen scientists and others who seek to access the UrtheCast imagery. To the extent compatible with NASA's mission needs, NASA will continue to support its partners, such as Nanoracks, and welcome additional opportunities to support commercial use of the ISS.

Question 9a:

Does NASA have a policy or process for reviewing or updating Space Act Agreements to ensure that they are complaint with U.S. laws, regulations, and policies? If so, please provide this policy or an explanation of the process.

Answer 9a:

NASA ensures that appropriate terms and conditions are included in each Space Act Agreement (SAA) at the outset, with updates as required by changes in the law. NASA Policy Directive (NPD) 1050.1 (please see link below) establishes responsibilities for negotiation, execution, amendment, and termination of SAAs. Per Section 5e, the NASA General Counsel (for Headquarters Agreements) or the Center Chief Counsel (for Center Agreements) is responsible for reviewing all Agreements entered into under this NPD to ensure compliance with applicable statutes, regulations, and policies.

http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_1050_0011_&page_name=main

Question 9b:

Has NASA taken any formal measures or analyses to determine if this arrangement could negatively impact the U.S. commercial remote sensing industry?

Answer 9b:

Via its Space Act Agreement with NanoRacks, NASA is supportive of a broader utilization of the ISS by non-traditional users. As such, it was expected that U.S. commercial firms may engage in partnerships with other-than-U.S. firms, just as is common in virtually any industry. It was not felt that this partnership with Urthecast presented any special challenges, nor did it circumvent the intent of the U.S. Commercial Remote Sensing Policy. The potential partnership between NanoRacks and Urthecast was carefully considered and deemed worthy of support, given the terms of the SAA with NanoRacks and the understanding that use of U.S. communication assets would be on a non-interference basis. Teledyne Brown, a U.S. company, is also testing Earth-imaging and hyperspectral measurement from ISS. This work is supported by a cooperative agreement.

Material requested for the record on page 47, line 1014, by Representative Brooks during the July 10, 2015, hearing at which Mr. William Gerstenmaier testified.

The Short Extravehicular Mobility Unit (SEMU) spacesuit cost $25M.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"The International Space Station: Addressing Operational Challenges"

Questions for the record, Mr. Bill Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

Question 1:

Several large ISS structural elements and parts were delivered to the ISS by the Shuttle, which had significantly greater cargo capacity than commercial cargo spacecraft. What are NASA's contingencies for replacing large parts such as solar arrays and radiators, once on-orbit spares have been used?

Answer 1:

With the exception of a replacement radiator and batteries, all other critical spares that might be required by ISS can be launched with Commercial Resupply Services (CRS) vehicles, and the heavy batteries that might be required for Station can be launched externally on Japanese H-II Transfer Vehicles (HTVs). The batteries, if absolutely required, could be transported by U.S. commercial providers, but the transportation and installation would be tremendously inefficient. Even in the case of the radiator, NASA is reviewing the prospects for breaking the radiator into component pieces that can be launched on separate vehicles. Solar arrays likewise can be packaged in a smaller ascent package and flown by U.S. commercial cargo providers.

Question 1a:

To what extent have advances in solar array technology and other ISS systems and structural elements enabled the potential for transporting replacement parts in a modular fashion that could potentially be accommodated on commercial cargo transportation vehicles to the ISS?

Answer 1a:

NASA does not anticipate having to replace Station's solar arrays for operations through 2024. Regarding modularizing other replacement parts, please see response to Question #1, above.

Question 1b:

Would use of the Space Launch System be an option?

Answer 1b:

The Space Launch System (SLS) will not be necessary for the transportation of spare parts to the ISS, and use of SLS for a LEO mission would be very inefficient, given that the vehicle has been designed for deep-space missions.

Question 2:

You have been quoted as saying that commercial crew services will increase the ISS crew size to seven, *"doubling the amount of crew time to conduct research"*. Once the crew size is increased to seven, will that crew member be focused almost solely on research or will the increased research time be spread across the crew members?

a. Is NASA planning to designate the seventh crew member as a payload specialist or scientist astronaut, as was done during the Shuttle era?

Answer 2 & 2a:

The specific assignments for the seventh crew member have not yet been determined.

Question 2b:

How much time is currently dedicated to research on a weekly basis?

Answer 2b:

As of the middle of ISS Increments 43-44, the average crew time being spent on utilization activities in the U.S. Operating Segment (USOS) was just over 40 hours per week. It should be noted that this includes crew personal time the astronauts have elected to spend on utilization activities, as well as scheduled utilization hours.

Question 3:

Dr. Pawelczyk's prepared statement states, *"Unless we improve our research centrifuge capabilities on the ISS, we accept a risk of sending humans to Mars with little or no knowledge of how mammalian biology responds in a gravitational field other than Earth's."* Does NASA have plans to improve the centrifuge capabilities on the ISS given its plan to extend ISS operations until at least 2024? If not, why not?

Answer 3:

NASA is working on developing a centrifuge capability that could accommodate rodent research. NASA is not planning for a centrifuge large enough to accommodate humans or other primates on ISS. The Japan Aerospace Exploration Agency (JAXA) is flying a small centrifuge for rodent research, and NASA will have access to that device.

Question 4:

Does NASA factor the risk of failures and losses of cargo into its estimated funding requirements for commercial cargo transportation? If so, how? If not, why not?

Answer 4:

While the loss of any cargo flight is a disappointment, NASA has planned for such mishaps. The CRS providers are not required to insure NASA cargo. While this keeps costs down for NASA, it also takes into consideration the likelihood of a mishap occurring at some point. The Agency and its international and commercial partners work to ensure that critical items can be remanifested and reflown quickly, and NASA does not manifest multiple high-value items of the same type on a single mission (e.g., spacesuits). With multiple vehicles providing dissimilar redundancy in the transportation of cargo to Station, the Agency and its partners work to minimize the impact of any single mishap.

Question 5:

The 2010 NASA Authorization Act directed NASA to designate a liaison to the National Lab management entity. Who is that liaison and what are his or her responsibilities?

Answer 5:

The National Laboratory liaison is the Director for ISS in the Human Exploration and Operations Mission Directorate. The liaison responsibilities include providing a strategic single-point interface for the coordination of ISS utilization for commercial entities, other Government agencies, and academic institutions. Other responsibilities include such activities as resolution of top-level programmatic issues, such as ISS resource utilization and coordination of outreach activities.

Question 6:

How will the Orbital ATK and SpaceX cargo mission losses inform NASA's approach to procuring future commercial cargo and crew transportation services? What changes, if any, is NASA considering making to commercial cargo and crew services procurement?

Answer 6:

In terms of cargo services, NASA is currently in a procurement blackout period in the award of CRS2. For crew, the Commercial Crew Transportation Capability (CCtCap) contracts have already been awarded and are being performed. Specific to the SpX-7 investigation activities, NASA will have the involvement of the Commercial Crew Program representative to provide insight into potential implications to that program.

Question 6a:

In light of the fact that recent events have demonstrated that both U.S. commercial suppliers could be unavailable due to accidents, do you anticipate continuing to arrange for use of the Russian Soyuz as a back-up capability to commercial crew transportation services to the ISS, beyond the 2018 and 2019 timeframe?

Answer 6a:

While NASA anticipates that U.S. commercial crew vehicles will begin flying in 2017, until a U.S. commercial vehicle is operationally available, the Soyuz is the only crew transportation and rescue vehicle available for continued access to crew launch, return and rescue services. NASA has recently contracted with the Russian Federal Space Agency (Roscosmos) on a sole-source basis for six Soyuz seats and associated services for calendar year 2018 with rescue and return services extending through late spring 2019 (in addition, we could potentially use these same seats through June 2020 to provide additional flexibility). Once U.S. commercial crew capability is established, NASA does not plan on acquiring Soyuz crew transportation capability. NASA crew members will fly on Soyuz and Russians on U.S. commercial vehicles for safe operation of the Station.

Question 7:

What is the impact of the recent cargo mission failures on NASA and NASA-supported research on the ISS, and what are NASA's plans for addressing those impacts?

Answer 7:

NASA, International Partner, and commercial research was lost in the cargo flight mishaps, but with the many experiments already on orbit, the most significant challenge to ISS research was the loss of crew time from the period of three-crew occupancy (about three weeks longer than planned). It was important to restore a six-person crew to ISS so astronauts could continue to conduct experiments already aboard Station. This was accomplished with the docking of Soyuz TMA-17M on July 22, 2015.

NASA and its international and commercial partners have demonstrated flexibility in the face of the cargo flight mishaps, as well as the importance of having different means for resupplying ISS. For example, NASA is reducing consumables margins to favor research on ISS. The Partners will continue to balance utilization and research to ensure that Station is flown safely and that impacts to research are minimized.

Question 8:

What, if any, modifications could be made on the ISS to help reduce the time the crew must spending preparing research equipment and increase the time the crew has for working directly on research activities? Are there any plans to make such modifications?

Answer 8:

Most of the hardware that can be automated to reduce crew time has already been automated. Crew time is currently spent on activities such as performing dissections and taking samples and stowing them in the freezers. These activities are very difficult to automate, as they involved life science samples and the crew's ability to discern which organ or sample to take is key in the execution of the science. Crew time is also spent on changing out sample containers to provide new materials, and preparing research equipment for operations. Once the sample is changed out, the system is operated remotely from the ground. The biggest crew time savings would be found by the addition of a second glovebox, which would allow one glovebox to be used permanently for physical sciences and one for life sciences research, thus eliminating the need for reconfiguration from one form to another. This second glovebox is in development now and expected to launch in early 2017. The other area where simplification of interfaces could minimize crew time is in the Japan Aerospace Exploration Agency (JAXA) airlock reconfiguration for different deployment uses. Work is ongoing in this area as well to prevent reconfiguration between uses of the airlock.

Question 9:

Dr. Pawelczyk testified that *"We can reasonably anticipate that competition for* [crew] *time will become worse as the facility ages and demands to perform necessary maintenance become more acute."* Do you agree? How will the aging of the ISS affect needed maintenance?

Answer 9:

U.S.-built Station modules were designed for a 30-year on-orbit lifetime and operations through at least 2024are technically feasible. NASA is tracking Station maintenance needs; at this point, a number of Station components are lasting longer than originally anticipated. In addition, enhancements to the baseline ISS systems to increase reliability and thereby decrease crew maintenance time are underway. For example, improvements to some of the life support components that have been more prone to failure are in work. These improvements will not only save precious crew time on ISS, but fill capability gaps for missions beyond LEO.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"The International Space Station: Addressing Operational Challenges"

Questions for the record, Mr. Bill Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate, NASA

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

Question 1:

In his written testimony, Mr. Elbon asserts that in the last 10 years, the ISS sustainment costs have decreased by 30 percent. How has NASA reallocated this reduction in sustainment costs?

a. Does NASA have a plan for reallocating this funding to research as operations costs decrease?

Answer 1 & 1a:

The FY 2016 President's Budget Request for O&M is $1.1B, a 36 percent reduction from the FY 2011 appropriation. The ISS Research budget has grown during the same period – from $176M in FY 2011 to $394M in FY 2016.

Question 2:

How does the ISS program compare to other programs at NASA in terms of contractors versus government employees?

a. Does the program have more government employees than usual?

Answer 2 & 2a:

No, the ISS program does not have more Government employees than usual. For comparison purposes, Exploration Systems Development (ESD) has approximately the same budget, but has more Government and contractor employees. It should be noted however, that the ISS contractor number cited below does not include ISS Crew and Cargo Transportation fixed price contracts where Work Year Equivalent (WYE) reporting is not required.

	ISS	ESD
FY 2016 Budget Request	$3.1B	$2.9B
Civil Servants	1,305	2,151
Contractor WYEs	4,286	6,426

Question 3:

It is my understanding that Boeing's current contract expires in September 2015. What is the status of negotiations for extension and to what extent has NASA put in place incentives for cost savings related to lowering operations costs?

Answer 3:

NASA has awarded a five-year, $1.18B contract extension to The Boeing Co. of Houston to continue engineering support of the ISS through September 30, 2020. Work under the contract extension is intended to maintain the station at peak performance levels so the full value of the unique research laboratory is available to NASA, its international partners, other U.S. government agencies and private companies. NASA continues to look for further opportunities to increase efficiencies, to allow us to productively operate and sustain the ISS, keep our crews healthy and safe, and support utilization at lower costs. Ongoing activities to decrease the O&M cost of the ISS include changes to our contracts to incentivize efficiency, lower overhead cost, and apply targeted enhancements in technology investments to reduce manpower-intensive processes.

Question 4:

If both SpaceX and Orbital ATK take longer than expected to resume cargo flights, would *Progress* or *HTV be* able to compensate for that by scheduling additional flights?

Answer 4:

NASA does not believe the scheduling of additional Progress or H-II Transfer Vehicle (HTV) flights will be necessary, even if there is a modest delay in the resumption of U.S. commercial cargo flights.

Question 4a:

What would this cost NASA?

Answer 4a:

Please see response to Question #4, above.

Question 5:

To what extent could the SpaceX failure impact commercial crew milestones generally?

Answer 5:

NASA does not anticipate that SpaceX-7 will affect the timeline for the Commercial Crew Program.

Question 5a:

How could these failures affect the planned design lock down at the delta critical design review later this year?

Answer 5a:

The lessons learned from this event could provide early insight to any needed design changes.

Question 6:

In 2014 the Aerospace Safety Advisory Panel recommended that NASA develop a formal plan establishing ISS's role in exploration technologies to provide purpose and constancy for ISS. What is the status of this recommended plan?

Answer 6:

NASA has an ISS Technology Demonstration Plan delineating key exploration capabilities; these include: Environmental Control and Life Support System (ECLSS); Environmental Monitoring; Extravehicular Activity (EVA); Fire Safety and Response; Crew Health and Performance Technologies; Thermal (including Cryo); Power and Energy Storage; Communications and Navigation; Structures and Materials; Radiation Monitoring and Shielding; Autonomous Operations; Automated Rendezvous and Docking; and Robotics. The Agency is also working on a plan for *In Situ* Resource Utilization (ISRU). The plan includes likely development and flight demonstration timeframes for these capabilities and is periodically updated based on recommendations from the NASA System Maturation Teams.

Question 7:

The NASA Authorization Act of 2010 directed NASA to conduct a comprehensive review to identify spare and replacement parts that utilization through FY2020 would necessitate. Has NASA conducted a similar review to support extension through 2024?

Answer 7:

With the ISS extension to 2020, the ISS Program undertook a comprehensive technical assessment for Station extension. In the process of doing this assessment, analysis for extending the ISS operations to 2028 was also undertaken, in case further extensions past 2020 were to occur. A status of this ongoing assessment was reported to the Congress in the ISS Sustainability Plan, which was called for in the FY 2014 Omnibus Appropriations Act (P.L. 113-76). A 2012 Government Accountability Office (GAO) audit (GAO-12-587T) found that NASA has a reasonable approach to meeting the challenge of estimating ISS spares and assessing Station's structural health and safety. In 2013, an independent Program Implementation Review examined ISS extension to 2020. In addition, the NASA Advisory Council (NAC) and Aerospace Safety Advisory Panel (ASAP) regularly review NASA's plans related to ISS, including the extension analysis. NASA has done an analysis that shows that the majority of

components are sustainable until 2028. A few components show end of life prior to 2024; however, additional analyses are being conducted to determine if more life is available or if additional steps will be required to extend life. These components are replaceable, if required.

Question 7a:

If so, what were its conclusions?

Answer 7a:

Please see response to Question 7, above.

Question 7b:

If not, will there be such a review? When will it be completed?

Answer 7b:

Please see response to Question 7, above.

Question 8:

NASA's Aerospace Safety Advisory Panel has recommended that "as NASA assesses ISS life extension, it should also review the objectives for continued ISS use and clearly articulate them to ensure that the costs and safety risks are balanced. Given that human space flight is inherently risky, that risk always needs to be weighed against the value to be gained by the endeavor." What process did NASA use to evaluate the balance between the value of achieving those objectives, on the one hand, and the costs and safety risks on the other?

Answer 8:

U.S.-built Station modules were designed for a 30-year on-orbit lifetime. The lifetime extension data that NASA and the ISS Partnership have reviewed to date indicates that extension to 2028 is technically feasible. The research and technology development we will conduct on ISS through 2024 will be essential to the safe and effective conduct of human exploration beyond LEO. This extension is also critical to commercial sector planning for the use of the ISS National Laboratory. Industry requires the planning stability provided by the extension in order to consider further investment in microgravity research and transportation services and allow time to enable and mature emerging commercial LEO markets. Commercial LEO development, spurred in part by the continuation of ISS, will also help enable exploration and make NASA resources available for deeper space exploration.

Question 9:

If ISS operations are extended to 2024, should Congress expect that in a few years, NASA will propose extending ISS operations again, perhaps to 2028?

Answer 9:

Any proposal for further extension would likely be based on the following transition indicators: whether critical deep-space technologies have been demonstrated; whether human health risks for deep space missions have been mitigated; whether NASA is ready to transition its human presence into the cis-lunar space proving ground; whether alternative platforms for conducting necessary research and technology development are available, and the demand outside of NASA for research in microgravity. It is important to remember, though, that NASA is focused on learning how to keep astronauts healthy and productive on ISS so that the Agency may focus on future deep-space missions beyond low-Earth orbit (LEO) into the proving ground of cis-lunar space.

Question 9a:

How will we know when it no longer makes sense to continue operating the ISS and that NASA funding would be better used for other exploration capabilities?

Answer 9a:

As noted above, NASA is focused on moving out beyond LEO into the proving ground of cis-lunar space. The Agency anticipates addressing most long-duration spaceflight risk areas through ISS and ground-based research by the mid-2020s; NASA would plan to address any remaining areas through missions in cis-lunar space or potentially through research conducted on other platforms. The transition indicators described above will further inform decisions regarding the appropriate time to discontinue ISS operations and transition fully into the proving ground. The amount of time required for ISS maintenance vs. research time will be another indicator.

Question 9b:

Is there a date beyond which further use of the ISS would not be possible?

Answer 9b:

Yes, the ISS lifetime is finite; however, at this point, NASA and the ISS Partnership have only assessed Station's extensibility out to 2028.

Question 10:

Recent reports in the press have indicated that Russia intends to back away from the ISS program after 2020. We've heard a lot of rumors come out of Russia lately; many of them seem to be simply speculation rather than state-level decisions.

a. Can you explain the situation as you understand it?

Answer 10a:

Roscosmos, has received government authority to continue ISS to 2024.

Question 10b:

How would Russia leaving the ISS partnership affect NASA's decision to extend ISS beyond 2020?

Answer 10b:

Please see response to Question #10a, above.

Question 10c:

How would this impact the Commercial Crew program, since launch is currently scheduled for 2017?

Answer 10c:

Please see response to Question #10a, above.

Question 10d:

Would NASA continue developing a system to only operate it for three years?

Answer 10d:

SpaceX's Crew Dragon and Boeing's CST-100 spacecraft will begin ferrying our crews to Station from U.S. soil by the end of 2017, contingent upon receiving the full amount requested in the FY 2016 Budget Request, enhancing the robustness of our transportation system and ending our sole reliance on Russia for the provision of these services. U.S. commercial crew capabilities will enable the Station crew to be expanded from six to seven astronauts and cosmonauts, resulting in a doubling of on-orbit research time to almost 80 hours per week. This is because the seventh crew member will be able to focus his or her time almost exclusively on conducting experiments, rather than on Station operations and maintenance. With over 350 American companies across 35 states working toward this goal, there are significant economic benefits to returning these launches to American soil. At the same time, every dollar we send overseas rather than investing at home represents an investment we could be making in ourselves rather than in the Russian economy.

As described in response to Question #10a, above, Roscosmos has received government authority to continue ISS to 2024.

Question 11:

Regarding the Orbital ATK accident, it is my understanding that you stood up your own investigative board independent of the Accident Investigation Board (AIB) required by FAA regulations.

a. Since the SpaceX accident involved the Falcon9.1launch vehicle that will be used for commercial crew, will you also stand up an AIB for this accident to provide an independent review? If not, what makes this accident different? If you plan to use a different process for investigating this accident, why the change?

Answer 11a:

NASA is performing an independent analysis of the SpaceX-7 launch failure. For the Orb-3 failure, we chose to establish a formal Independent Review Team (IRT) to amplify the learning for the NASA teams. We chose to do a similar thing for the SpaceX failure, conducting an independent review, but using existing mechanisms that were already in place.

Like the Orbital ATK Antares launch, the SpaceX-7 launch was conducted under an FAA license, and was therefore not considered a NASA mishap; however, in the case of the Falcon 9, the Launch Services Program (LSP) has two contract launch service task orders in place with SpaceX under our NASA Launch Services II (NLS II) contract for the launch of two high-value payloads on the Falcon 9 launch vehicle. NASA's NLS II contract allows NASA to stand up its own independent review or assessment team for an anomaly or launch failure of a launch vehicle directly applicable to an on-contract launch service, and the commercial launch service provider is contractually bound to support and cooperate with NASA's independent team. In addition, NASA Policy Directive (NPD) 8610.7 *Launch Services Risk Mitigation Policy for NASA-Owned and/or NASA-Sponsored Payloads/Missions*, and NPD 8610.23 *Launch Vehicle Technical Oversight Policy* are incorporated into the NLS II contract. NPD 8610.7 requires a post-flight assessment be performed by LSP of every launch of every vehicle certified or in the process of being certified for use under the NLS-II contract. Per this NPD, "[r]esolution of all flight anomalies and mission failures is required by the launch service contractor with Launch Service Program (LSP) technical evaluation and disposition" [emphasis added]. NPD 8610.23 calls out specific data, products, processes, events, etc. into which LSP shall be provided insight by the commercial launch provider and lists specific events and items over which LSP has approval authority. The LSP review will provide the same benefit to NASA's other programs utilizing SpaceX (ISS and Commercial Crew) as the IRT for Orbital-ATK.

Question 12:

NASA released an announcement that it plans to procure seats on the Soyuz vehicle beyond 2017. If NASA plans to have the Commercial Crew contracts ready to go by the first quarter of 2018, why is it necessary to procure these seats?

Answer 12:

While NASA's Commercial Crew providers are on track to provide certified crew transportation systems in 2017, transition to a fully operational system will take time and requires the funding requested in the FY 16 President's Budget. NASA needs to have the ability to rotate crew in the event of a pad problem or development problem in the Commercial Crew Program. The Soyuz seats allow for a safe start to operational commercial crew capability.

Question 12a:

What happens if the contractors are ready in time and we don't need the seats?

Answer 12a:

NASA plans to utilize the seats once purchased. The procurement will be used to ensure proper launch vehicle cadence or augment ISS operations and research capabilities, as required. Flight priority will go to the U.S. commercial crew capability providers. The Soyuz seats will allow for extra crew time, which is presently a constraint to research operations.

Question 12b:

Does this mean the FY16 budget request may be for more than is necessary?

Answer 12b:

No; please see response to Question #12a, above.

Question 12c:

How much lead time do you need to cancel a seat that was purchased for a Soyuz flight and when is the payment for that flight made?

Answer 12c:

Please see response to Question #12a, above.

Question 13:

In your written testimony, you state that the cost per seat for Commercial Crew will be $58M versus $76M for seats from Russia. Does this $58M include the CCDev and CCiCap funding? What would the cost per seat be if you did include these costs?

Answer 13:

The estimated Commercial Crew seat price cited is specific to the Commercial Crew Transportation Capability (CCtCap) contracts. The previous Commercial Crew Development (CCDev) and Commercial Crew Integrated Capability (CCiCap) efforts were separate activities, and are not considered part of the contract price. Nether the Soyuz price nor the commercial price consider development costs.

Question 14:

The NASA Authorization Act of2010 requires NASA to build the *Orion* crew vehicle with a minimum capability requirement to provide backup crew transfer services to the ISS in the event that commercial contractors are unavailable. This does not require *Orion* to be launched on SLS. The Administrator has said in the past that the Orion will not be used for this purpose. The law does not permit NASA that flexibility.

a. In the event that both Commercial Crew contractors experience failures similar to the Commercial Cargo program, do you believe it would be a bad idea to use Orion rather than rely on Russia?

Answer 14a:

NASA is complying with the NASA Authorization Act of 2010 -- the Orion design could accommodate ISS crew transportation requirements. NASA anticipates that commercial crew transportation services to ISS will be available in 2017. This is the fastest way to achieve crew transportation capability. If this is not the case, and if Russian Soyuz services are also unavailable, NASA would focus all efforts on utilizing Orion. This would force a major shift in development for Orion and could possibly involve another launch vehicle other than SLS. There would also be major modifications to plans at KSC. This would be a highly inefficient use of the Orion, which is a crew vehicle that is primarily designed for deep space exploration and, if needed for an emergency, could function as a backup vehicle for the ISS crew. The current Orion design is specifically designed and tailored for deep space exploration and a high-speed reentry to Earth, which includes systems that are not necessary for LEO missions. Launching the Orion capsule for use in LEO would also be an inefficient use of a robust system intended for other purposes.

Question 15:

At present, Orbital ATK does not have a rocket in service for transporting the *Cygnus* cargo vehicle, SpaceX will not be flying its rocket in the immediate future as it investigates its recent failure, and the Russians only recently returned their *Progress* resupply spacecraft to flight using a previous configuration of the launch vehicle. Given the current situation we find ourselves in, would it not be prudent to have a backup capability for crew transfer services should we find ourselves in a similar situation with the Commercial Crew program, as required by the NASA Authorization Act of 2010?

Answer 15:

Please see response to Question 14, above. In addition, Cygnus is scheduled to fly on an established rocket Atlas V on December 3, 2015. This was done at no additional cost and provides cargo capability.

Question 16:

NASA dedicates approximately 9.8 percent of the ISS budget to research. There are several requirements in federal law for NASA to utilize the space station for scientific research to the maximum extent practicable. Do you believe that requesting only 9.8 percent of your budget for research is fulfilling that requirement?

Answer 16:

NASA's budget for ISS includes a balance of systems operations and maintenance; research; and cargo/crew transportation. The ISS supports research across a diverse array of disciplines, including high-energy particle physics, Earth remote sensing and geophysics experiments, molecular and cellular biotechnology experiments, human physiology research (including bone and muscle research), radiation research, plant and cultivation experiments, combustion research, fluid research, materials science experiments, and biological investigations. In addition, the ISS is an invaluable platform for technology development efforts. Research and development conducted aboard the ISS holds the promise of next-generation technologies, not only in areas directly related to NASA's exploration efforts, but in fields that have numerous terrestrial applications. The ISS will provide these opportunities to scientists, engineers, and technologists through at least 2024.

NASA's Human Research Program continues to develop biomedical science, technologies, countermeasures, diagnostics, and design tools to keep crews safe and productive on long-duration space missions. The progress in science and technology driven by this research could have broad impacts on Earth as it advances our ability to support long-duration human exploration.

Fully utilizing the ISS for research and technology development continues to be a top priority for NASA. Increment 43/44 includes 298 investigations across the areas described above, and the ISS research crew time is fully subscribed.

Question 17:

GAO's written testimony asserts that the success of the ISS is largely dependent to the success of CASIS because of the amount of research capacity dedicated to the national lab. Do you agree with this assessment?

Answer 17:

It is very important for the potential of ISS as a National Laboratory to be realized. Use of the

ISS as a National Laboratory has increased significantly since FY 2012, which was the first full year of operations by the Center for the Advancement of Science in Space (CASIS). CASIS has reached its full allocation of National Lab resources and it expected to continue to do so for the foreseeable future. Commercial projects for research and technology development on the ISS National Lab have increased from three in FY 2012 to 107 in FY 2014. Similarly, use by other Government agencies, including the National Institutes of Health and Department of Defense, has also begun to broaden, totaling 11 investigations in FY 2014. Finally, investigations from academic institutions rose from 31 in FY 2012 to 90 in FY 2014. Grant funding for research through the National Lab continues to grow, from $2.1M in FY 2012, to $5.9M in FY 2014.

Question 17a:

How do you work with CASIS to maximize the use of their allocation on cargo flights and for astronaut research time?

Answer 17a:

NASA takes into consideration actual on-orbit needs and performance as well as increment science priorities as established by the COUP (Consolidated Operations and Utilization Plan). These needs and requirements are then balanced against the flight readiness and capabilities of the individual flight vehicles. NASA works across the partnership and science stakeholders, including CASIS, to ensure that their needs and priorities are being met.

Question 17b:

What process has NASA and CASIS developed to plan for efficient utilization of this allocation?

Answer 17b:

While NASA's ISS Division acts as the liaison between the Agency and CASIS, the Division does not manage CASIS or determine the research priorities for use of ISS as a National Laboratory. CASIS uses a multi-tiered approach to evaluating potential research: operations feasibility, scientific goodness, economic value, and commercial viability – these drive priorities. NASA believes this will help ensure that research from a wide range of disciplines is carried out aboard ISS.

Question 18:

There were CASIS experiments aboard the SpaceX-7 flight that were remanifested from the Orb-4 flight. Essentially, these experiments have been lost twice now. What is NASA's plan for remanifesting this research?

Answer 18:

NASA will remanifest these experiments as soon as CASIS indicates that they wish them to be

remanifested – as early as SpaceX-9 or OA-4 if the hardware is available. NASA is providing manifest priority to research over consumables and spares margins.

Question 18a:

Did NASA and CASIS develop this plan prior to the accident or did you develop it in real-time?

Answer 18a:

The recovery plans for all lost NASA and CASIS payloads began following the accident. The manifest is always dynamic, and the Agency makes every attempt to fly research hardware as soon as it is requested. After an accident like Orb-3 or SpaceX-7, replanning of the manifest for the next flight begins immediately as data on what needs to fly and is available to fly are provided. The manifest protected for the loss of three cargo vehicles with minimal impact to ISS operations.

Question 19:

Flying research on the ISS is not a simple endeavor, it is incredibly complicated and requires years of planning. This has been an obstacle to commercial utilization of the ISS in the past. What challenges do NASA and CASIS need to overcome to assure commercial entities that doing research on the ISS is worthwhile?

Answer 19:

NASA and CASIS have been focusing on streamlining the processes for flying research on the ISS. In August of 2014, ISS started the Revolutionize ISS for Science and Exploration (RISE) effort that is focused on reworking all of the ISS processes, many of which are heritage from the Space Shuttle days, to ensure that only the work required to fly research safely is required of the payload developer. Requirements have been simplified to the point that only approximately 1/3 of the previous requirements will still be applicable to research payloads. Safety definitions of "critical" and "catastrophic" have been changed as part of the RISE process to be simplified for payloads compared to systems. The payloads integration flow is being shortened to be able to accommodate going from concept to on-orbit data returned to the payload developer in 12-15 months.

Question 19a:

How can you mitigate these challenges in light of the loss of two cargo ships within months of each other?

Answer 19a:

NASA is reducing consumables margins to favor research on ISS. While research was lost on the cargo flight mishaps, there is significant research to do on orbit, so it was important to restore a six-person crew to ISS so astronauts could continue to conduct experiments already aboard

Station. This was accomplished with the docking of Soyuz TMA-17M on July 22, 2015.

Question 20:

How have the recent cargo accidents affected the ISS crew's ability to devote time to research?

Answer 20:

Crew time is at a premium on ISS, and the period during which ISS had a three-person crew (about three weeks longer than planned) affected the astronauts' ability to devote time to research. The six-person crew complement was restored when Soyuz TMA-17M docked to ISS on July 22, 2015.

Question 20a:

How has the loss of experimental equipment in those accidents affected ISS research facility occupancy?

Answer 20a:

NASA, International Partner, and commercial research was lost in the cargo flight mishaps, but with the many experiments already on orbit, the most significant challenge to ISS research was the loss of crew time from the period of three-crew occupancy.

Question 20b:

How has the loss of other types of cargo affected the research capabilities of the ISS?

Answer 20b:

Significant non-research cargo (e.g. a spacesuit, International Docking Adaptor, multi-filtration beds) was lost, but this did not directly impact the research capabilities of ISS.

Question 21:

The argument for the use of the ISS is largely dependent on return on investment and assured access to the ISS. How have the cargo accidents impacted utilization from the perspective of potential commercial investors?

Answer 21:

NASA defers to potential commercial investors to characterize the impacts of the cargo flight losses on their prospective use of ISS. Anecdotally, though, at an ISS users conference held in Boston shortly after the loss of SpX-7, it was made clear that

potential Station users continue to be very enthusiastic about conducting microgravity research on board ISS. In addition, the diversity of types of potential users continues to grow.

Question 21a:

How can NASA mitigate the risks to utilization associated with these types of accidents?

Answer 21a:

NASA and its international and commercial partners have demonstrated flexibility in the face of the cargo flight mishaps, as well as the importance of having different means for resupplying ISS. The Partners will continue to balance utilization and research to ensure that Station is flown safely and that impacts to research are minimized. Again, one key to doing this is to maintain a six-person crew complement on Station so that research can be carried out to the fullest extent.

Question 22:

As a result of the *Progress* and *Cygnus* launch accidents, NASA and the international partners delayed the launch of additional crew leaving only three crewmembers on board. What is the real-world result of only having three crew members on the ISS?

Answer 22:

Please see response to Question #20, above.

Question 22a:

How does a three-member crew effect utilization and operations of the ISS?

Answer 22a:

ISS can be operated safely with only three crew on board, but research time is significantly limited.

Question 23:

How do NASA and Boeing work together to maximize the use of the ISS for deep space exploration efforts? Is there an integrated plan for this research that includes the needs of all the various divisions of human exploration or is there another mechanism for pursuing this work?

Answer 23:

ISS plays a key role in preparing for crewed missions into the proving ground of cis-lunar space, and eventually to Mars. Station is critical for both life science research required to keep our

crews safe and productive on long-duration missions, and for the development of exploration technologies to be incorporated into those missions. In addition to the ISS Technology Demonstration Plan described in the response to Question #6, above, NASA also uses the Human Research Program's (HRP) risk reduction plan, which is designed to chart progress in reducing the risk in 25 human health and performance areas important to deep-space exploration, including a mission to Mars. These plans are coordinated across the Human Exploration and Operations Mission Directorate and the Space Technology Mission Directorate.

Question 24:

In 2013, the NASA Inspector General recommended that "in order to better assess the performance of CASIS, [NASA should] work with CASIS to develop precise annual performance metrics that measure CASIS's success at fostering private research on the ISS." GAO has now recommended the same thing in its most recent report.

a. What metrics does CASIS currently use to measure its effectiveness?

Answer 24a:

CASIS measures its effectiveness with a variety of metrics, including: ISS Utilization; Pending Projects; Request for Proposals Review Efficiency; Expenses : Funding; New Projects Funded; Total Grant Value; Compliance Training; Partnerships Created; Funding Commitments Received; Social Media Metrics; Media Reach; Outreach; and Active Science Technology, Engineering, and Mathematics (STEM) Programs. Current statistics can be found at: http://www.iss-casis.org/Dashboard.aspx

NASA measures CASIS based on its performance of the tasks agreed to with NASA.

Question 24b:

What are the current values of those metrics, and how do they compare to the target values?

Answer 24b:

At a top level, NASA tracks CASIS' utilization of National Laboratory resources as a measure of effectiveness, with a goal of utilization of 50 percent of Station's resources. For Increment 43-44, CASIS is projected to approach or surpass this in the areas of upmass and crew time, though downmass is projected to be less than in previous recent Increments. Beyond this, CASIS reports on a variety of quarterly metrics, and will be reporting on annual metrics, as well.

Question 24c:

Who sets the target values, CASIS or NASA?

Answer 24c:

Performance metrics are negotiated by NASA and CASIS.

Question 25:

CASIS claims that intellectual property statutes may deter some potential commercial research on ISS. Please provide some specific examples. Why does research on the ISS require different intellectual property laws or regulations at other federal facilities, such as NASA's wind tunnels or the Department of Energy's national laboratories?

Answer 25:

Commercial users of the ISS National Lab through the CASIS cooperative agreement are subject to the same intellectual property laws applicable to any entity working with NASA through a cooperative agreement. There are no special or different intellectual property requirements specifically applicable to research on the ISS.

Commercial users of NASA wind tunnels or Department of Energy (DoE) national laboratories typically access those resources on a fully reimbursable basis. That is, they fully fund the cost of the Federal resources being provided to support them. That is not the case for entities utilizing the ISS through the CASIS cooperative agreement.

NASA has reviewed whether it can provide preferred consideration of intellectual property rights for users of the ISS and had determined that it cannot under its current statutory authority.

As NASA seeks to maximize the use of ISS and its National Laboratory capacity, the Agency is reviewing this issue to ensure that potential commercial users will not be deterred from pursuing the research potential of Station.

Question 26:

Two metrics for evaluating ISS research utilization are the ISS crew time devoted to research and the occupancy of ISS research facilities. How many hours per week does the ISS crew currently spend on research?

Answer 26:

As of the middle of ISS Increments 43-44, the average crew time being spent on utilization activities in the U.S. Operating Segment (USOS) was just over 40 hours per week. It should be noted that this includes crew personal time the astronauts have elected to spend on utilization activities, as well as scheduled utilization hours.

Question 26a:

What is the current percentage of ISS research facility occupancy?

Answer 26a:

As of the end of FY 2014, the occupancy was 65 percent. This value is updated at the end of each fiscal year.

Question 26b:

How do these compare to NASA's goals and to past trends?

Answer 26b:

Crew time spent on utilization exceeds the goal of 35 hours per week. This number could be approximately doubled with the addition of a seventh crew member after Commercial Crew vehicles begin flying in 2017.

Question 26c:

Are there other more appropriate metrics such as peer reviewed articles, citations, or outcomes?

Answer 26c:

There are many metrics available to chart the progress of research aboard ISS. For example, for Expeditions 0-present, there have been over 1,000 scientific results publications; more than 500 researchers represented; and over 1,939 investigations in total (Pending Post-Increment Adjustments).

Question 27:

In 2011, the National Research Council issued its first decadal survey of NASA's life and physical sciences research on the ISS. In 2012, NASA stated that the results of the decadal survey would be incorporated into future NASA research solicitations, and that a decadal survey evaluation committee would reconvene annually to evaluate progress. What changes has NASA made in the past four years as a result of the decadal survey's recommendations?

Answer 27:

NASA has responded in detail to both the administrative and technical recommendations of the Decadal Survey. Key administrative recommendations of the survey:

- Establish program leadership with "true scientific gravitas";
- Position the management of the biological and physical sciences with appropriate visibility to senior agency leadership;
- Establish regularly issued solicitations to engage the external scientific community;

- Establish a research advisory committee; and
- Establish effective data sharing to allow the scientific community to participate more fully in space research.

In response, NASA established a division within the Human Exploration and Operations Mission Directorate (HEOMD) to manage the biological and physical sciences. The Division Director is a direct report the Associate Administrator for HEOMD, giving the division a high level of visibility within human spaceflight.

To establish leadership with "scientific gravitas," NASA solicited applications from senior industrial and academic researchers, and selected Purdue professor Dr. Marshall Porterfield to serve as the director of the Space Life and Physical Sciences Research and Applications Division.

Research solicitations have been released annually in both the biological and physical sciences, and the size of the community receiving support from NASA has grown steadily over the past four years.

NASA has established two separate advisory committees to provide advice on the management of the life and physical sciences. A standing committee of the National Research Council (NRC) Space Studies Board, the Committee on the Biological and Physical Sciences in Space, provides strategic recommendations and oversees the Decadal Surveys, in a manner completely consistent with the NRC's role in NASA's other science programs. NASA has also created a committee within the structure of the NASA Advisory Council, the Research Subcommittee of the Human Exploration and Operations Committee. The Research Subcommittee advises NASA management on the implementation of the research program.

Data sharing is a major initiative in both the biological and physical sciences, with the creation of new data systems and the solicitation of research using archive data in planning.

The technical recommendations of the survey span a wide range of scientific fields, with over 60 specific "highest priority" recommendations. These recommendations are referenced in NASA's research solicitations, and the proposals that are received in response are assessed for their adherence to the recommendations of the survey. However, merit review by independent technical experts remains the primary basis for determining the technical merit.

Question 27a:

Does the evaluation committee continue to reconvene annually?

Answer 27a:

Both the NRC Committee on Biological and Physical Science in Space and the Research Subcommittee of the NASA Advisory Council normally meet twice a year.

Question 27b:

What are some of the major conclusions?

Answer 27b:

The minutes of the Research Subcommittee are available at the website:

http://www.nasa.gov/directorates/heo/library/nac/nac_research_subcommittee.html#.Vds_hkiCbv0

Past findings have included an endorsement of the effort by the Space Biology program to reach out to investigators not previously supported by NASA; an endorsement of the GeneLab concept to bring contemporary "-omics" analytical technologies (-omics refers to a system-level approach to studying molecular biology; examples include genomics, proteomics, and metabolomics) to the conduct of space biology and human research; and support for the quality of the community currently engaged in space research.

Question 28:

What fraction of the experiments conducted on the ISS require a return capability?

Answer 28:

At least one-third of all ISS research utilizes a return capability, including almost all of the HRP and life sciences, and many of the physical sciences experiments. Examples are samples from the crew on HRP experiments, life sciences research on rodents, fruit flies, cells, and microbial investigations, and physical science samples like coarsening and solidification experiments.

Question 29:

NASA and CASIS seek to demonstrate that commercial markets in low-Earth orbit are viable and can be sustained. What do you define as a commercial market in low-Earth orbit and what is NASA's interest in this goal?

Answer 29:

One of NASA's goals is to promote U.S. economic activity in low-Earth orbit (LEO). A commercial market in LEO could include the production of goods and/or the provision of services that would be available to a range of customers (i.e., beyond NASA itself). NASA is interested in promoting a LEO economy to strengthen the larger U.S. economy, to obtain reliable cargo and crew transportation services at competitive prices, and to enable the Agency to focus its efforts on developing deep-space exploration capabilities, such as the Orion crew vehicle and the Space Launch System (SLS) heavy-lift launcher, by transitioning investments in LEO to the commercial sector

Question 29a:

What role will NASA have to play to ensure such markets are sustainable?

Answer 29a:

NASA is encouraging commercial activity in LEO through the purchase of cargo and crew transportation services, and by supporting commercial research aboard the ISS National Laboratory. This latter effort includes NASA's provision of launch services to National Lab users, as well as crew time and Station infrastructure (e.g., power) free of charge. In addition, NASA and CASIS are looking at other ways to enable LEO markets through targeted consortia initiatives. It is hoped that all of these efforts will lay the foundation for ongoing commercial efforts in these and other areas even after the end of ISS operations. There may be future, non-governmental space stations in LEO that will continue some of the research begun aboard ISS, with U.S. domestic transportation providers offering their services to the user community.

Question 30:

Do you agree with Dr. Pawelczyk's testimony that the ISS is missing critical components for research that would be important for learning how human physiology would respond in fraction gravity environments?

Answer 30:

NASA is working on developing a centrifuge capability that could accommodate rodent research. NASA is not planning for a centrifuge large enough to accommodate humans or other primates on ISS. The Japan Aerospace Exploration Agency (JAXA) has a rodent centrifuge capability that will be available for U.S. researchers.

Question 31:

In your written testimony you state that "NASA's plans for research through 2017 are based on having six crew members on ISS including the Human Research Program objectives we need to accomplish during this period to keep on track to reduce or retire risks for deep-space exploration." At the moment you only have three crew members aboard the ISS. How do the accidents with cargo flights affect NASA ability to keep the ISS crewed with 6 astronauts and what is the impact to your research schedule for the Human Research Program?

Answer 31:

As noted in the response to Question #20a, above, it is important to maintain six crew on ISS to ensure that the research capability of Station is maximized. As long as the unplanned periods of three-crew staffing are minimized, any impacts of such periods should be mitigated. The ISS returned to six-crew operations with the launch of Soyuz 44S on July 22, 2015.

Question 32:

This week NASA released the annual "Benefits to Humanity" book. Can you summarize for the committee what you believe are the most important benefits the American people have received from the ISS?

Answer 32:

The ISS is a unique scientific platform that enables researchers from all over the world to put their talents to work on innovative experiments that could not be done anywhere else. In the areas of human health, innovative technology, education and observations of Earth from space, there are already demonstrated benefits to people back on Earth. Lives have been saved, Station-generated images assist with disaster relief, new materials improve products, and education programs inspire future scientists, engineers and space explorers. From pharmaceutical companies conducting commercially-funded research on ISS, to private firms offering unique research capabilities and other services, to commercial cargo and crew, the ISS is proving itself to be just as adaptable to new business relationships as it has been for a broad diversity in research disciplines.

Question 32a:

What type of intangible benefits does the Nation receive from the ISS?

Answer 32a:

The research and technology demonstrations onboard the ISS are providing the basis for extending human presence beyond the bounds of LEO and taking our next steps into the proving ground of cis-lunar space. The ISS is vital to NASA's mission to extend human presence into the solar system. The ISS has been home to a continuous human presence on orbit for almost 15 years – it is a beachhead on the frontier of space, and one that enables us to work together with our international partners while demonstrating global leadership in human spaceflight and technology development. ISS is performing research that benefits people on Earth many of which are described in "International Space Station – Benefits for Humanity" (2nd Edition):

https://www.nasa.gov/sites/default/files/atoms/files/jsc_benefits_for_humanity_tagged_6-30-15.pdf

Question 33:

The NASA Authorization Act of 2010 required NASA to stand up an advisory board called the ISS National Lab Advisory Committee, or INLAC. In response to GAO's report that NASA is not fulfilling the requirement of the law, NASA responded that it is unnecessary because the board of directors for CASIS fulfills this role.

a. Has NASA ever submitted a request to Congress to change this law? If not, why? What is NASA's reason for not requesting this change?

Answer 33a:

NASA acknowledges the need to submit a request to Congress in order to change this law, and the Agency is reviewing this issue.

Question 34:

Mr. Gerstenmaier, this past March, your directorate announced 12 Next STEP commercial awards for technology development projects that will enable deep space exploration and advance our understanding of system requirements and capabilities that may be tested on the International Space Station. Have you given consideration to utilizing some of these technologies to improve efficiency and reduce operational costs for current space systems like the ISS?

a. In particular, I know one of these technologies, the VASIMR Engine, is being tested for deep space Solar Electric Propulsion but has multiple capabilities, including ISS re-boost. I understand this re-boost approach could be more efficient and could save NASA multi-millions of dollars as opposed to the propellant used and services currently provided by the Russians. What are your thoughts on this subject?

Answer 34 & 34a:

VASIMR is a promising propulsion technology, though there are concerns that would preclude the system from being installed on ISS for reboost capability. Among these are funding issues, questions about the installation site on ISS, and the need to fly and recharge batteries to support limited-duration thrusting. Ultimately, the system would not be a significant contributor to Station reboosts, which are already provided by Progress cargo vehicles. Additionally, the power required for VASIMR reboost is not compatible with the power available on ISS.

If results from the other Next Space Technologies for Exploration Partnerships (NextSTEP) BAA contracts lead to enhanced capabilities for the ISS, NASA will consider implementation through follow-on efforts. An example could be enhanced ECLSS capabilities that would improve reliability, reduce crew maintenance time, or other resource requirements associated with the baseline ISS ECLSS.

Responses by Mr. John Elbon

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"The International Space Station: Addressing Operational Challenges"

Questions for the record, Mr. John Elbon, Vice President and General Manager, Space Exploration, The Boeing Company

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. Boeing is responsible for the operations and maintenance of the ISS. This is a complex endeavor that involves thousands of people and man hours. Can you explain what the process of integrating and operating the ISS actually entails for Boeing?

Integrating and operating the ISS is a very complex endeavor. Continuity of design, build, and maintenance is paramount to successful integration and operation. Boeing's long history with the ISS has maintained continuity between requirements development, hardware production, integration, and ultimately extended operation of the most complex laboratory in the world. Boeing's extensive experience with international partners, as well as its own commitment to cultural awareness help form a cohesive team that is necessary for an undertaking the magnitude of ISS. Boeing's role supporting NASA as the integrator brought together not only the US contractors as a team, but also seamlessly integrated the international partner countries and their suppliers into a global team to make ISS successful. Boeing is a global company with cultural diversity that understands the engineering nuances of multiple countries. This experience has been leveraged to provide clear communication of initial requirements, to resolve issues during development and assembly, and continues to pay dividends as we provide sustaining engineering services to the ISS. Additionally, Boeing manages and has access to one of the largest supply chains in the world. This ensures more affordable solutions and efficient implementation on the ISS, from normal maintenance of life-limited parts, to development of new and innovative approaches for demonstrating technology which will be used on future exploration missions beyond low earth orbit (LEO). Boeing's ability to reach back into Boeing-industry for innovative solutions has allowed the ISS to operate beyond its intended life and will allow the ISS many more years of important scientific research.

   a. How does Boeing work with the international partners to respond to anomalies or any one of the many possible interruptions to normal operations?

NASA is responsible for the international partners' participation and contributions to the space station program – Boeing supports NASA, and integrates the international partners through NASA, to maintain, sustain, and support the operations of ISS. Boeing is able to leverage numerous well established international partnerships, from both the Boeing Defense & Space, and the Boeing Commercial Airplane sectors of the company. These strong and established relationships with international governments and contractors make Boeing uniquely suited and qualified for this work. In practice, each partner is responsible for identifying, reporting, investigating, tracking, and resolving problems and anomalies which affect on-orbit International Space Station (ISS) systems, hardware, software, and operations. The ISS Mission Evaluation Room (MER) personnel (Boeing and NASA) are responsible for oversight and integration of international partner anomalies that impact both sides of a physical or

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functional interface. When an anomaly is determined to be integrated, the ISS MER will lead the anomaly investigation with the participation of affected organizations, unless otherwise directed by the ISS Program. This general criteria also applies to the ISS systems-to-payload experiment interface and the ISS-to-CRS visiting vehicle interface. The ISS MER will lead the investigation into international integrated anomalies through Multilateral Anomaly Resolution Team (MART) meetings. The purpose is to understand the anomaly, identify integrated impacts which includes both safety of crew and vehicle, and the implementation of workarounds and/or recovery. All technical data provided by our international partners is assessed by ISS MER system engineering teams as part of the MART. These MARTs can be one time meeting or could lead into multiple meetings over a period of time until resolution. In addition, the ISS MER proactively holds bi-weekly meetings with the USOS international engineering counterparts in Roscosmos, the Canadian Space Agency, the European Space Agency's (ESA) Columbus Engineering Support Team (COL EST), and Japan's JAXA Engineering Team (JET) to provide system status which includes partner anomalies that are isolated to their systems, or anomalies that could potentially have integrated impacts to ISS.

2. In your written testimony, you assert that in the last 10 years, the ISS sustainment costs have decreased by 30 percent. What is being done to decrease future ISS operations costs?

In the upcoming contract period of FY 16-20, Boeing will reduce costs further by continuing its commitment to LEAN principles and continuous process improvement. Specific areas of emphasis include: efficiencies within the sustaining supplier base and the ability to optimize their support while still maintaining critical skills and meeting program requirements; reductions in status meeting support and frequency; implementation of NASA's Revolutionize ISS for Science and Exploration (RISE) efficiencies to increase science and research utilization without increasing labor costs; review and removal/risk based application of requirements that drive cost; increased partnering with small disadvantaged business (SDB's) across the country; adoption of COTS tools rather than upgrades or maintenance of obsolete tool sets where cost effective; combining/streamlining of Logistics deliverable data products; proactive approaches to parts and materials obsolescence to reduce cycle time for spares; efficiencies in job assignments/functions within the teams to optimize performance; reduction in frequency of data product deliveries and simplification of formats; simplification of data trending reports, streamlining cost and schedule reporting between NASA and Boeing, and Boeing and suppliers.

3. According to figures briefed to the Committee by GAO last year, your ISS workforce was projected to decline by over 400 people from FY14 to FY15. What is the status of this reduction and how is it being accomplished?
    a. What were these people working on that is no longer necessary?

Boeing emphasizes continuous improvement to increase affordability and efficiency. This is

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achieved in part by improving our understanding of the operating environment and capabilities of the ISS vehicle and systems. As such, sustaining engineering tasks include efforts to increase the operational flexibility of the ISS vehicle. For example, use of the US-segment (USOS) control moment gyros (CMG's) for attitude control has been approved for a broader range of operational configurations, such as for certain dynamic events that previously were performed under Russian thruster attitude control only. This expanded capability has reduced the amount of propellant used, and simplified the effort required to coordinate these dynamic events across international partners. This ultimately reduces the overall work load of the ground team and crew, and represents a net reduction in the cost of operations. When possible we improve efficiency by freeing up engineers and technicians to support other programs, while maintaining their expertise for reach back capability. This approach reduces costs to the ISS program while allowing Boeing to provide the skills necessary and maintain bench strength.

4. Boeing's current contract expires in September 2015. What is the status of negotiations for extension and to what extent has NASA put in place incentives for cost savings related to lowering operations costs?

Contract negotiations are continuing and we expect to settle prior to end of FY15. No gap in contractual coverage or performance is expected. NASA and Boeing are working together to continue to emphasize affordability as a constant focus, while maintaining the highest priority on safety and quality, with incentives provided by the contract award fee structure.

5. As a result of the *Progress* and *Cygnus* launch accidents, NASA and the international partners delayed the launch of additional crew leaving only three crewmembers on board. What is the real-world result of only having three crew members on the ISS?

a. How does a three member crew effect utilization and operations of the ISS?

Utilization, along with all of ISS operations can be substantially impacted by extended periods with only three crewmembers, since it represents a 50% reduction in available crew time. However, the impact to reduced crew size is highly dependent on the activities planned for the time period in question. In the most recent example over the summer of 2015, the impacts were minimized by re-scheduling/re-prioritizing activities to maximize the utility of the available crew. Some tasks were pulled forward and done as "get-aheads", while other activities were delayed to a time when they could be completed with a full crew complement. More specifically, the delay of the 43S launch resulted in four additional weeks with one US crew, reducing the amount of crew time available for science and maintenance by

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approximately 268 hours. To maintain a focus on science, the NASA/Boeing operations team deferred the crew tasks required to support planned ISS reconfiguration activities and deferred scheduled maintenance of core systems. The deferral of core maintenance was closely evaluated by our engineering team to ensure the risk was minimized by such deferrals. The loss of the SpaceX Dragon capsule resulted in the cancellation of approximately 100 hours of crew time that was allocated for the transfer and stowage of cargo from the Dragon capsule. This crew time was utilized to perform the overdue maintenance. Additionally, due to the loss of one of the space suits on Dragon, the crew performed additional maintenance on one of the space suits on orbit to return it to an operational status. Due to the diligence of our teams in Houston, Huntsville, and across the globe, we were able to overcome the challenges from the loss of the Progress and Cygnus. The overall impact to utilization, from a crew time perspective, due to the loss of the Progress, Cygnus, and Dragon vehicles was only ~100 working hours over the course of the last 6 months. The teams continue to work through the long term impacts given the loss of these vehicles and the subsequent impacts to available crew time. We are confident in our ability to overcome these challenges and posture ourselves, and the ISS, to be even more prepared to respond to similar challenges in the future. Finally, it should be noted that with the advent of Commercial Crew capability, the crew size will increase from 6 to 7 at times, and this alone represents a 50% increase in utilization capability because at least one crew member can be nearly 100% dedicated to research.

6. How do NASA and Boeing work together to maximize the use of the ISS for deep space exploration efforts?

The ISS is an ideal platform to conduct the research and system demonstrations needed to validate long duration human spaceflight required for future deep space exploration missions. As NASA's contractor for ISS sustaining engineering, Boeing is responsible for maintaining the station and ensuring the full availability of the unique research laboratory currently being used as a test bed to conduct the research and technology demonstrations necessary to keep our crews safe and productive on long-duration deep space exploration spaceflights. In that role, Boeing works on projects that configure the ISS, and integrates and sustains the advanced systems enabling various technologies to be tested over time on the ISS. Examples of ISS projects that Boeing is working on include:

- *The NASA Docking System (NDS) which is the next generation docking system to be used in space. ISS will be outfitted with the docking adaptor in the very near future. The NDS is the system used on the Boeing CST-100 commercial crew and cargo vehicles that allows it to dock to the ISS. NASA's ORION crew vehicle will also use the NDS allowing it to dock to habitation systems in deep space.*
- *Communication systems that enable more efficient mission and ground operations are needed not only for the ISS but for future exploration missions that are more earth independent. Boeing is working to implement a delay tolerant communication capability, Delay Tolerant Network (DTN), which not only will be useful for enhanced communications on the ISS but will demonstrate capability needed for the long distances and delayed communication in deep space.*

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- *Approaches to augment the current ISS solar arrays capability are being considered due to expected degradation of existing solar arrays over the coming years. With our extensive commercial solar electric satellite experience and in-depth understanding of solar array technology Boeing studied the feasibility of integrating an advanced solar array on the ISS. The approach considered the use of advanced solar array technology that once demonstrated on ISS could be a candidate for high powered solar electric propulsion systems for deep space exploration spaceships.*
- *Basic crew needs drive tremendous logistics challenges for mission planners. Efforts must be made to reduce basic life support system weight and volume for long duration human missions to the Moon and Mars. The best way to do this is to develop next-generation hardware and learn through iteration and experience how well it works and how to make it better. The ISS is the ideal place to test, demonstrate and assess a complete single string advanced life support system to prepare for long duration, human missions in deep space. Boeing is currently assessing how to integrate an advanced life support system on ISS using ECLSS technologies defined by NASA The approach considers the use of advanced life support systems, which once demonstrated on ISS could be a candidates for deep space exploration spaceships as well as Moon and Mars surface habitation systems.*
- *The ISS has provided an excellent platform and proving ground/environment to observe the performance of modern micro-electronics in a high radiation environment. There was a time when we were very concerned that the thin substrates of the newer Pentium class chips would be very susceptible to radiation damage, however we have learned a lot in that area as we have employed further upgrades that employ even higher technology micro-electronics. The use of advanced electronics that can withstand long duration exposure to radiation is critical to the success of our exploration beyond LEO, and we are learning from our experiences on ISS with every day and every orbit that passes.*

While NASA and Boeing work very closely together as part of the ISS Program, there are activities separate from our ISS sustaining engineering role whereby we work with NASA to maximize the use of ISS for deep space exploration. Boeing entered into a public-private partnership with NASA on the Next Space Technologies for Exploration Partnerships (NextSTEP) to further develop habitation system capabilities to be used for human spaceflight exploration missions in the cis-lunar space and beyond. This partnership leverages millions of dollars of Boeing corporate investment in habitation system concepts and related research and development. Boeing's approach here is to maximize the application of proven ISS capabilities and to mature the needed advanced technologies to the degree they can be ready and operated as the next generation habitation system built for cis-lunar space missions. In addition, Boeing engineers are compiling lessons learned from ISS and applying them to concept and feasibility assessments that will lead to the development of next generation of habitation systems for future deep space exploration spaceships.

Is there an integrated plan for this research that includes the needs of all the various divisions of human exploration or is there another mechanism for pursuing this work?

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NASA has an integrated plan for research that includes the needs from various divisions including the Human Exploration Operations Mission Division, Space Technology Mission Directorate, and Science Mission Directorate.

7. Of the four available cargo spacecraft, only the SpaceX *Dragon* is capable of returning cargo to Earth. How would an extended hiatus in this capability affect the use of the ISS for research?

There are five available spacecraft (SpaceX Dragon, OA Cygnus, HTV, Soyuz and Progress) that visit the ISS. Both SpaceX Dragon and Soyuz have the ability to return cargo to Earth, although the Soyuz return volume is significantly limited.

Even with an extended hiatus in return capability, on-orbit scientific research can continue for a significant period of time. However, there is limited cold stowage available for biological and life science (human and plant) samples on-board ISS. The Minus Eighty Laboratory Freezer for ISS (MELFI) is the primary storage facility for payload cold stowage samples, and based on current projections the MELFI would be completely full by May 2016 if there were no additional SpaceX returns. Eventually, these samples must be returned to continue on-board science. There is a small volume return capability on Soyuz but it is very limited and historically biological samples have not been returned on Soyuz.

a. What fraction of the experiments conducted on the ISS require a return capability?

The fraction of the experiments that require ISS return capability varies significantly from one Increment to the next. For the next few Increments approximately 30 to 40% of the experiments operating within the Increment pair require return capability. Over the past several increments (since May 2014, Increment 40) the average required return capability was approximately 40%. If SpaceX-7 would have returned as planned the return rate would have approached 50%.

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Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. Several large ISS structural elements and parts were delivered to the ISS by the Shuttle, which had significantly greater cargo capacity than commercial cargo spacecraft. What contingency options are available for replacing large parts such as solar arrays and radiators, once on-orbit spares have been used?

There are very few replacement items that cannot be delivered to the ISS via one of the existing cargo vehicles. For large items like radiators and solar arrays, Boeing has performed preliminary studies for smaller replacement devices that can be launched aboard current visiting vehicles. New solar array technologies yield more power per square meter thus reducing the size required for replacing failed or degraded arrays. The program has leveraged design options developed by DARPA to propose auxiliary solar arrays that can be retro-fitted to the existing array structure. The program has also invested in modifications to pump module design to allow smaller packaging of critical ORU's to facilitate replacement on-orbit.

2. How have Boeing and NASA sought to reduce ISS operations costs, and what amount of cost avoidance has been realized?

In the last five years Boeing has reduced the ISS sustaining cost by over 10% per year beyond the impact of inflation in the economy. When cost avoidance is included by completely offsetting inflation between 2011 and 2020, NASA and Boeing will have avoided more than $600M over the 10 year period. Boeing and NASA partner to minimize cost of sustaining, as well as spares, repairs and modifications through LEAN principles, and constant vigilance to avoid over applications of requirements while ensuring the safety, security and quality of ISS products and services. Specific areas of emphasis in the next contract period include: efficiencies within the sustaining supplier base and the ability to scale back their support while still meeting program needs; reductions in status meeting support and frequency; implementation of NASA's Revolutionize ISS for Science and Exploration (RISE) efficiencies to affect a reduced headcount; review and removal/risk based application of requirements that drive cost; increased partnering with small disadvantaged business (SDB's) across the country; adoption of COTS tools rather than upgrades or maintenance of obsolete tool sets where cost effective; combining/streamlining of Logistics deliverable data products; proactive approaches to parts and materials obsolescence to reduce cycle time for spares; efficiencies in job assignments/functions within the teams to optimize performance; reduction in frequency of data product deliveries and simplification of formats; simplification

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of data trending reports, streamlining cost and schedule reporting between NASA and Boeing, and Boeing and suppliers.

Would you anticipate any changes or increased demands on operations and maintenance should ISS operations be extended until 2024?

Boeing anticipates that maintenance demands will increase as the ISS ages, although we see no evidence that these increases will be outside what our models predict. Hardware design requirements are closely reviewed and logistics impacts and maintenance considerations are taken into account from initial development. This includes minimizing life limited subassemblies, providing capability to repair and replace subassemblies, developing on-orbit I-level maintenance capabilities, supporting ground repairs, and performing preventative maintenance to ensure hardware life is maximized. Annual supportability analyses are performed based upon hardware operation, utilization, and failure trends. Near, mid, and long term needs are identified to proactively determine sparing, repair, and refurbishment needs. The last sparing analysis performed in early 2015 predicted that over 60% of the hardware ORUs have sufficient spares to last through 2029, and risk mitigation strategies, such as procurement of spares and repair parts, for the majority of the remaining items. In conjunction with this, hardware obsolescence is monitored daily and future parts needs are considered to allow for procurements now in support of future repair needs. As the program continues to age, there is also the option to modify system operations to account for degraded hardware functionality and to rely more heavily on I-level maintenance actions.

3. Your testimony referred to improvements on ISS made to *"further enhance research capabilities"*. What are those improvements?

Some of the most significant improvements include the following: additional space-to-ground (S/G) communication channels to enable principle investigators (PI's) to talk directly to the crew; increased ability for high quality video downlink; increased data down/uplink; command and telemetry capability using internet protocols via Stella (IP encapsulation); additional video downlink channels enabling simultaneous payload operations; 110 VAC power interface for COTS products; higher quality and resolution cameras to take advantage of increased downlink capability; external wireless access; and improved payload commanding via KU forward link using standard internet protocols.

Are there additional improvements being planned or considered to enhance research and, if so, what are they?

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Additional improvements that are planned include the following: web-based access; 4th crew to increase crew time to average 68.5 hours per week; high definition video of external ISS from multiple locations (pan, tilt, zoom, still images); consolidated logistics; wireless ethernet; telemetry and video; enhanced communication and networking coverage; flash freezer; additional external sites; second science glove-box; Enhanced Processor and Integrated Communications (EPIC); Air to Ground (A/G) High Rate Communications System (HRCS); on-orbit external wireless high rate; and, additional EXPRESS payload racks.

4. Dr. Pawelczyk testified that *"We can reasonably anticipate that competition for* [crew] *time will become worse as the facility ages and demands to perform necessary maintenance become more acute."* Do you agree? How will the aging of the ISS affect needed maintenance?

Boeing agrees that the replacement of failed hardware with spares will escalate in future years as hardware reaches end of life. However, ISS hardware has been and is being designed to minimize crew time maintenance needs during change-out or preventative maintenance actions. Additionally, new hardware has been developed to supplement existing designs in order to minimize or completely eliminate crew time demands. For example, the Advanced Recycle Filter Tank Assembly (ARFTA) fill and drain modification kit was designed to eliminate the need for the crew to remove the ARFTA tank every 10 days from the rack to be emptied and replaced. This one modification for implementation in 2015 is expected to save 32 hours of crew time per year. The program continues to proactively search for improvements to implement other crew time savings initiatives. The program will be challenged in the future to troubleshoot anomalies that may not be directly traceable to individual hardware items. The program has and continues to identify additional hardware that can be used for troubleshooting or in a contingency situation to restore functionality, using a modified architecture.

Responses by The Hon. Paul K. Martin

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The Honorable Paul K. Martin, Inspector General, NASA

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. **To what extent could the SpaceX failure impact commercial crew milestones generally?**

   a. **How could these failures affect the planned design lock down at the delta critical design review later this year?**

   Answer: We initiated a follow-up review of NASA's Commercial Crew Program in May 2015 and are examining these and other questions as part of that audit.

2. **In your report on feasibility of extending the ISS you raise concerns about NASA's projections for the cost of extension as overly optimistic. Specifically, you state, "the program's independent government cost estimates project significantly higher costs when the Agency transitions to purchasing these seats from commercial companies."**

   a. **What do these higher costs mean for the utilization of the ISS?**

   Answer: Higher costs could result in fewer missions to the ISS and require resources to be diverted from other Agency priorities. In our 2014 report, NASA officials conceded that any substantial budget savings would likely come from flying fewer missions than planned.

   b. **Do you believe the Commercial Crew Program will be cheaper than buying seats from Russia or using a scaled back Orion on an existing EELV?**

   Answer: We plan to assess Commercial Crew Program costs as part of our ongoing audit.

3. **Commercial Crew contractors and NASA remain confident that they will provide capability by 2017. To what extent do you share their confidence given the current situation of our commercial cargo providers?**

   Answer: The timetable for commercial crew flights is another issue we are examining as part of our ongoing audit. If there were slippage in the schedule, it would most likely be related to funding shortfalls and/or issues certifying the companies' systems as safe for human travel.

4. **Two metrics for evaluating ISS research utilization are the ISS crew time devoted to research and the occupancy of ISS research facilities. How many hours per week does the ISS crew currently spend on research?**

   Answer: In our September 2014 audit regarding extension of the ISS, we reported the ISS crew was spending approximately 39.4 hours per week conducting research, exceeding NASA's goal of 35 hours per week. ISS Program Managers would be able to provide the most current information regarding this metric.

   a. **What is the current percentage of ISS research facility occupancy?**

   Answer: NASA has 19 laboratory bays and 15 external sites that house research experiments on the ISS. The laboratory bays, which contain racks, freezers, and other infrastructure that support biological, life science, and other types of experiments, are located in the U.S., European, and Japanese labs. The external sites, located outside the ISS, are used primarily for astronomical studies, Earth observation, and technology development and demonstrations for robotics, materials, and space systems. In our September 2014 audit, we reported an occupancy rate of 80.7 percent for the laboratory bays in the U.S. portion and a rate of 37.5 percent for the external sites as of March 2014. We also reported NASA expected these rates to rise to 86.3 percent and 55 percent, respectively by September 2014. Again, ISS personnel may have more current information.

   b. **How do these compare to NASA's goals and to past trends?**

   Answer: Given that the occupancy rates from 2011-2012 were 70 percent and 31 percent respectively, the numbers we reported represent a substantial improvement over time.

   c. **Are there other more appropriate metrics such as peer reviewed articles, citations, or outcomes?**

   Answer: Because no one measure provides a complete picture of utilization rates, NASA utilizes three primary data points to assess utilization of ISS research capabilities: average weekly crew time, number of investigations, and use of allocated space. While imperfect, these are reasonable metrics for assessing research utilization.

5. **What risks to long duration spaceflight beyond low Earth orbit will not be mitigated by NASA research on the ISS through 2020? What about through 2024?**

   Answer: In our September 2014 audit, we reported NASA had identified 23 types of human health and performance risks associated with long-term space exploration that can be mitigated aboard the ISS. Extending ISS operations until 2024 would put the Agency in a better position to address 12 of these risks, including

decompression sickness, reduced muscle mass, fatigue-induced errors, and cardiac rhythm problems. In comparison, NASA would have time to address only 5 of the 23 risks should ISS operations end in 2020. While continued operation of the ISS until 2024 will allow for the mitigation of additional risks, NASA will be unable to address 11 types of risk on the ISS by 2024:

(1) Human-computer interaction (planned mitigation for December 2025) – risk of inadequate human-computer interaction.
(2) Inadequate food system (planned mitigation for December 2026) – risk of performance decrement and crew illness due to an inadequate food system.
(3) Errors due to training deficiencies (planned mitigation for December 2027) – risk of performance errors due to inadequate training.
(4) Occupant protection (planned mitigation beyond 2028) – risk of injury during launch and landing.
(5) Early onset osteoporosis (planned mitigation beyond 2028) – risk of early onset of osteoporosis due to spaceflight.
(6) Altered immune response (planned mitigation beyond 2028) – risk of crew adverse health event due to altered immune response.
(7) Bone fracture (planned mitigation beyond 2028) – risk of bone fracture during mission.
(8) Unpredicted effects of medication (planned mitigation beyond 2028) – risk of clinically relevant unpredicted effects of medication during mission.
(9) Vestibular/sensorimotor impacts (planned mitigation beyond 2028) – risk of impaired control of spacecraft, associated systems, and immediate vehicle escape due to coordination issues.
(10) Behavioral conditions (planned mitigation beyond 2028) – risk of adverse behavioral conditions and psychiatric disorders.
(11) In-flight medical capabilities (planned mitigation beyond 2028) – risk of unacceptable health and mission outcomes due to limitations of in-flight medical capabilities.

We are updating the status of NASA efforts to mitigate these risks as part of our ongoing audit of NASA's Efforts to Manage Health and Human Performance Risks for Space Exploration, which we plan to issue this fall.

a. What plans does NASA have to retire those risks prior to any long duration spaceflight missions?

Answer: Our upcoming report will address this issue.

6. **In your report on the extension of the ISS, you cited a concern that even if the ISS was extended to 2028, NASA would likely be incapable of completing all the research necessary to mitigate its target risks for long-duration human space flight. What should NASA be doing to mitigate this risk?**

   Answer: As recommended in our 2014 report, NASA has prioritized risks so that ISS research time will be dedicated to mitigating the most critical risks first. As noted above, our upcoming report will provide more detailed information about the steps NASA is taking to mitigate risks and will provide additional suggestions for improving that process.

7. **Are there any other portions of the NASA Authorization Act of 2010 or requirements for the ISS that NASA is not following?**

   Answer: While we have not conducted a comprehensive assessment of NASA's compliance with the NASA Authorization Act of 2010, we are not aware of any particular portions of the Act with which NASA is not complying.

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The Honorable Paul K. Martin, Inspector General, NASA

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. **Several large ISS structural elements and parts were delivered to the ISS by the Shuttle, which had significantly greater cargo capacity than commercial cargo spacecraft. What are NASA's contingencies for replacing large parts such as solar arrays and radiators, once on-orbit spares have been used?**

   Answer: NASA prepositioned more than half of its $1.1 billion replacement part inventory on the ISS before retirement of the Shuttle. The Agency can transport Solar Array Wings and Heat Rejection Subsystem radiator replacements by sending smaller, redesigned models on the current fleet of cargo spacecraft. In terms of future transportation, Orbital has designed a cargo vessel that could carry large replacement units, and SpaceX is developing a heavy lift version of its Falcon launch vehicle. However, neither vehicle is expected to be available until 2016 at the earliest. Until then, NASA is using the Japanese H-II Transfer Vehicle to deliver large items like the Lithium-Ion batteries that will replace the current Ni-H2 batteries and provide electricity when the Station is in the eclipse portion of its orbit.

   a. **What have your analyses found regarding NASA's ability to accommodate failures on large parts?**

   Answer: In our 2014 report on ISS extension, we examined NASA's response to the unanticipated degradation of the Station's solar arrays, which use motors to position themselves toward the sun. Both the arrays and the motors have degraded more quickly than expected. We reported ISS Program officials had several options to compensate for the faster-than-expected degradation rates. First, the Russians plan to deliver a module (the Scientific Power Module) around 2019 that will increase the Station's capability to generate power and eliminate the need for the U.S. segment of the Station to provide the Russian segment with power. Second, the ISS Program has the option to reconfigure the orientation of the solar arrays so they will generate more power. Program officials believe the Station will be able to meet its power requirement once the Russians deliver their module and, if needed, the solar arrays can be reoriented to a position that maximizes exposure to sunlight. For the Solar Array Wing motors, the Agency has decided to perform a return-and-repair plan only if the motors lose full function.

b. How likely are such failures predicted to be prior to 2020, and then to 2024?

Answer: NASA has certified the U.S. segment of the Station and the Zarya module, which the Russians constructed but the U.S. owns, for operation through 2020. At the time of our September 2014 report, the Agency had not identified any major structural, hardware, or software deficiencies that would prevent continued operation of the ISS until 2024.

Responses by Ms. Shelby Oakley
Questions from Chairman Brian Babin

1) **How does the ISS program compare to other programs at NASA in terms of contractors versus government employees?**

   a. **Does the program have more government employees than usual?**

   There are no other current NASA programs in operations that support human habitation in space and that would provide a comparison to the ISS program. Workforce data from the retired Space Shuttle program when it was in operations could provide a relevant comparison, but that information would have to be supplied by NASA in order for GAO to respond to your question.

2) **What can NASA do to ensure that the ISS program has the necessary spare parts to sustain a life extension to at least 2024 while balancing the need to lower operations costs?**

   If NASA weighted actual performance more heavily in its calculations of spare parts requirements, in general, the need to purchase additional spare parts could decline, which would lower operations costs. In December 2011, we reported that NASA's approach was reasonable for determining, obtaining, and delivering orbital replacement units, that is, spare parts, to the ISS through its then-planned 2020 lifespan.[1] At that time, NASA calculated for each ISS subsystem the required type and quantity of spare parts based on (1) how long the parts were lasting on orbit, and (2) their designed life expectancy. NASA's calculations gave equal weight to the actual performance of the subsystems on orbit and to the manufacturers' original reliability estimates of how long the subsystem components should last. As we noted in that report, NASA found that in some cases parts were failing faster than designed or expected, but overall spare parts were exceeding manufacturers' design predictions. As a result, we recommended that as the ISS program accumulated additional knowledge about the on-orbit performance of spare parts, the NASA Administrator should direct the ISS program manager to revisit, as appropriate, the relative weight given to on-orbit performance versus the manufacturers' original reliability estimates. NASA concurred with our recommendation and has since periodically reviewed the weights used to determine how many spare parts to purchase. Officials have indicated, however, that NASA still considers its current approach appropriate and therefore has made no adjustments to weight actual performance more heavily than predicted performance. We continue to believe, however, that as the ISS accumulates on-orbit performance data, adjustments to the weighting could provide NASA potential opportunities to reduce ISS operations cost by offering a more accurate assessment of spare parts needs. In addition, in those limited circumstances when parts are failing faster than projected, NASA would ensure that parts are on hand to address failures in a timely manner.

   NASA could also lower ISS costs by continuing efforts to streamline ISS operations. The ISS program has implemented a number of initiatives that have yielded cost savings or containment. For example, NASA reduced operations costs by scaling back ISS program and contractor workforce levels and by combining several contracts. The NASA

[1]GAO, *International Space Station: Approach for Ensuring Utilization through 2020 Are Reasonable but Should be Revisited as NASA Gains More Knowledge of On-Orbit Performance*, GAO-12-162 (Washington, D.C.; December 15, 2011).

Inspector General currently has ongoing work assessing NASA's efforts to combine and consolidate ISS contracts for operations and maintenance and should be able to provide detailed information regarding the program's progress in these areas.

3) **To what extent could the SpaceX failure impact commercial crew milestones generally?**

    a. **How could these failures affect the planned design lock down at the delta critical design review later this year?**

As of August 2015, it is unclear what effect the SpaceX failure may have on the commercial crew milestones. Commercial Crew program officials told us that they are still assessing the effects of the June 2015 mishap on the schedule.

4) **In your written testimony, you state that crew and cargo transportation to the ISS is projected to increase in cost by over $700 million between 2015 and 2020. How does this compare to what NASA would have paid to our international partners absent the commercial crew and Cargo programs? Is this more or less expensive?**

NASA could provide more detailed information for a comparison of costs if the commercial crew and cargo programs were not available. However, NASA on average will pay Russia $76.3 million per seat in 2017 for crew transportation. NASA recently took steps to purchase six Soyuz additional seats from Russia for about $490 million—or approximately $82 million per seat—for flights to the ISS in 2018, the cost of which ISS program officials said was accounted for in the program's projected transportation costs. ISS program officials told us that in fiscal year 2017, the program will begin to fund commercial crew missions that are expected to take place in fiscal year 2019. The cost for seats purchased from SpaceX and Boeing for commercial crew flights in 2019 are less than the cost of Soyuz seats in 2017.

5) **Your written testimony indicates that NASA has been working to cut costs for the operations and maintenance of the ISS. What are the challenges associated with reducing these operations costs? Has NASA lost any capability or other benefits from the station as a result of these reductions?**

We have not assessed whether NASA has lost any capability or other benefits as a result of reductions in the ISS operations and maintenance costs. The NASA office of the Inspector General recently issued a report focused on the service life extension of the ISS in which it identified potential risks that will require mitigation.

6) **In your written testimony, you state that while costs of ISS operations will increase by approximately $130 million from 2017-2020 due to inflation, the funding for ISS research will not increase by a similar percentage. Can you explain the difference? Does NASA not expect inflationary effects for research and science programs?**

This question would be best directed to NASA since we cannot speak for NASA's reasons behind its budget planning. However, the approximately $130 million planned increase in ISS operations costs generally occurs between fiscal years 2017 and 2018, then the ISS program projects that operations costs will be level through fiscal year 2020. In our written statement, we reported that inflation is only one component of the overall projected increase. NASA also attributes the increase to the addition of a fourth

crew member. It should be noted that there was an increase in ISS operations costs in fiscal year 2011 when the program was planning for the service life extension of the ISS from 2015 to 2020.

7) **Commercial crew contractors and NASA remain confident that they will provide capability by 2017. To what extent do you share their confidence given the current situation of our commercial cargo providers?**

We are concerned about the likelihood that the commercial crew capability will be available in 2017. Both Boeing and SpaceX have compressed schedules and are currently planning to hold their certification reviews in 2017. If the partners experience delays to address risks, their certification reviews could be delayed.

8) **In your written testimony, you indicated that CASIS spends an average of 28 percent of its budget on grants for research on board the ISS. What did GAO's analysis of this funding allocation demonstrate about the ability of CASIS to fulfill the requirements of its mandate from the NASA Authorization Act of 2010 and their cooperative agreement with NASA?**

In April 2015, we reported that CASIS had taken steps to fulfill its responsibilities contained in its cooperative agreement with NASA, and had initiated the activities required by the NASA Authorization Act of 2010.[2] For example, CASIS identified key research areas, released seven requests for proposals to solicit interest for research projects, and was building a geographic network to facilitate outreach initiatives and cultivate new partnerships. We also reported, however, that there are no measurable targets or goals for CASIS's performance metrics to know what success means for CASIS's efforts to increase utilization of the ISS National Laboratory.

9) **The argument for use of the ISS is largely dependent on the return on investment and assured access to the ISS. How have the cargo accidents impacted utilization from the perspective of potential commercial investors? How can NASA mitigate the risks to utilization associated with these types of accidents?**

We cannot comment on the perspective of commercial investors. However, securing commercial investments will likely be key to CASIS's success. CASIS officials said that it takes time to identify, develop, and mature partnerships with organizations to secure external funding. CASIS and NASA officials said that the value of doing research aboard the ISS National Laboratory has to be further demonstrated so commercial industries can be convinced it is worth the high investment. Both NASA and CASIS officials said that demonstrating the value of research on the ISS as a substitute for ground-based research is a tremendous and important effort that is necessary to open a marketplace for space research. Launch failures and delays only serve to delay such a demonstration.

10) **In your written testimony, you stated that CASIS reported that, through December 2014, it had received approximately $12 million from external sources but that its 2014 report only identified contributions of $9,193. Can you explain this discrepancy?**

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[2]GAO, *International Space Station: Measurable Performance Targets and Documentation Needed to Better Assess Management of National Laboratory*, GAO-15-397 (Washington, D.C.: April 27, 2015).

In the written testimony, we stated that, through December 2014, CASIS reported that it had received funding commitments from external sources of approximately $12 million to support its research mission. These commitments can include cash gifts, pledges, in-kind gifts, and other types of support that have a monetary value in support of the CASIS mission. In fiscal year 2014, these commitments yielded $9,193 in actual cash contributions.

11) Your recent report on CASIS discusses the need to implement measurable targets and goals for CASIS's annual performance metrics. What would doing this provide?

a. What is lacking without these targets?

Having measurable targets would allow NASA an objective basis to assess CASIS's performance and support decision making for future funding of CASIS and whether to extend the cooperative agreement. In our April 2015 report, we found that NASA and CASIS had not established measurable targets or goals for CASIS's performance metrics. We have previously reported that performance metrics should have quantifiable, numerical targets or other measurable values.[3] Without these targets, NASA and CASIS cannot conduct assessments of CASIS's efforts to increase ISS utilization that are objective, measurable, or conclusive.

12) Your written testimony outlines several areas of concern regarding utilization of the ISS. What do you see as the key priorities to help NASA and CASIS expand research on low earth orbit?

NASA has made an important commitment to the future of research aboard ISS by proposing to extend operations to 2024. Key to supporting this commitment is effectively managing the challenges, such as demand for crew time and certain research facilities and CASIS's ability to raise additional funding from external sources, that could affect efforts to maximize the return on investment for the tens of billions of dollars that have been spent on the ISS. Achieving greater utilization of the ISS and its unique capabilities, showing the benefit of commercial and academic research, and demonstrating success to generate increased interest from potential users could help NASA demonstrate such a return. Because CASIS is allocated at least 50 percent of ISS U.S. research capacity allocation, ensuring that CASIS continues to make progress promoting research activities and achieving its goal to increase utilization of the ISS is essential.

13) The NASA Authorization Act of 2010 required NASA to stand up an advisory board called the ISS National Lab Advisory Committee, or INLAC. In response to GAO's report that NASA is not fulfilling the requirement of the law, NASA responded that it is unnecessary because the board of directors for CASIS fulfills this role. Are there any other portions of the NASA Authorization Act of 2010 or requirements for the ISS that NASA is not following?

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[3]GAO, *Tax Administration: IRS Needs to Further Refine Its Tax Filing Season Performance Measures*, GAO-03-143 (Washington, D.C.: Nov. 22, 2002).

Our work was focused specifically on assessing the extent to which CASIS had initiated and implemented the required activities for non-NASA research aboard the ISS National Laboratory as required in section 504(c) of the 2010 act. As detailed in our report, we found that CASIS has taken steps to carry out its responsibilities to manage and promote research activities on the ISS National Laboratory as outlined in its cooperative agreement, with the exception of coordinating with the INLAC. The NASA Authorization Act of 2008 directed NASA to establish the INLAC, but the agency has yet to staff that committee.

Questions from Ranking Member Donna Edwards

1) **Several large ISS structural elements and parts were delivered to the ISS by the Shuttle, which had significantly greater cargo capacity than commercial cargo spacecraft. What are NASA's contingencies for replacing large parts such as solar arrays and radiators, once on-orbit spares have been used?**

   a. **What have your analyses found regarding NASA's ability to accommodate failures of large parts?**

      During our 2011 review of the International Space Station, ISS program officials indicated that if the program were to exhaust available pre-deployed spares for large items such as solar arrays and radiators before the ISS end of life, NASA could continue to operate the ISS at a reduced operational capacity. Alternatively, they said, NASA could potentially develop replacements that could be disassembled, transported to the ISS within the available transport spacecraft, and reassembled in orbit at the space station. The officials stated, however that there would be a significant expense associated with developing and deploying these types of replacements.

   b. **How likely are such failures predicted to be prior to 2020, and then to 2024?**

      GAO has not conducted any analyses regarding NASA's ability to accommodate failures on large parts or any analyses predicting the likelihood of such failures prior to 2020 or 2024. NASA, however, evaluates the ISS sparing needs on an annual basis and is in the process of conducting a comprehensive assessment of the structural health of the ISS. Consequently, the ISS program office should be able to provide detailed answers to this question based on these analyses.

2) **In your prepared statement, you indicate that ISS Operations costs (not including transportation) are expected to remain relatively stable through FY2020. Does your assessment show ISS operations costs remaining stable even as the ISS ages? If so, what is the basis for the assessment?**

   GAO's assessment was based on the budget profile in NASA's President Budget Estimates for fiscal years 2015 and 2016 for the ISS program and historical budget information provided by the program which provided data through fiscal year 2020. GAO has not been provided any assessment of the costs to extend the ISS beyond 2020. Our past work on Department of Defense (DOD) aircraft systems, however, indicates that

operations costs increase as those systems age.[4] There may be factors that could increase operations costs for the ISS over time such as the need for additional spare parts and the need to implement mitigations to address structural issues.

[4]GAO, *Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapons Systems*, GAO-10-717 (Washington, D.C.: July 20, 2010).

Responses by Dr. James A. Pawelczyk

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September 10, 2015

The Honorable Brian Babin
Chairman, Subcommittee on Space
Committee on Science, Space and Technology
Congress of the United States
House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515-6301

Dear Mr. Babin:

Thank you for the opportunity to respond to your follow up questions from the hearing "The International Space Station: Addressing Operational Challenges" held on July 10, 2015. Written responses to your questions are provided below. These are my personal opinions; they do not necessarily represent those of my employer or the advisory groups with whom I consult.

1. **In your written testimony you mention the necessity of the extension criteria report in the NASA Authorization Act. As a retired NASA astronaut and now as a researcher, how would you describe NASA's long-term cohesive plan for how to maximize ISS utilization and tools to define it as a research success?**

A number of metrics are commonly used to define research success. Chief among these are measures that incorporate the number of peer-reviewed research publications resulting from research, adjusted for the typical number of citations for the article (e.g., impact factor, H-index). These are appropriate measures that most research-sponsoring federal agencies track and report.

Research productivity is not synonymous with research success. For the ISS, success is best measured by the extent to which research contributes to achieving the goal of placing humans on Mars. This information is codified in NASA's Human Risk Reduction Roadmap. Summary information for Congress should include progress toward mitigating these risks for exploration-class missions (i.e., those that exceed one year in duration).

As I stated in my testimony, the ISS Sustainability Plan indicates that some risks will not be completely mitigated, even at the conclusion of the extension period. This is not necessarily a reflection of research program adequacy as much as it is a reflection of unclear programmatic goals. In other words, a program that needs to provide for any possible exploration scenario cannot possibly mitigate all risks. Thorough task analysis of proposed mission designs helps keep the research program focused on exploration goals.

Simply put, at the conclusion of the ISS program we should understand, from a biological perspective, enough to successfully send and return humans to the Martian surface (or any other mission of similar duration). There can no more important goal for having a long duration research platform in low-earth orbit.

A note of caution is in order: fundamental or "discovery" science has lowest priority within NASA today, with allocations of research time that are alarmingly low. In my opinion, Congress would be wise to provide direction on the allocation of time between National Laboratory and NASA sponsored research; perhaps focusing National Laboratory research on either discovery science (freeing NASA time allocations for more exploration focused research) or vice-versa. Either direction will require more coordinated efforts between National Laboratory activities and NASA-sponsored activities on the ISS. Emphasizing "return on investment" metrics with short time horizons (< three years) is unlikely to result in a research portfolio that emphasizes either discovery science or long-duration human exploration of space.

In plain language, NASA needs a stronger voice in the direction and implementation of National Laboratory activities.

2. As Congress debates the extension of the ISS to 2024, what do you see being the major obstacles to utilization of the station from the point of view of a researcher?

There are four major obstacles to utilization:

a) Availability of up-mass to transport payloads to the ISS
b) Powered and pressurized cargo space during ascent and descent to stabilize and/or condition biological payloads
c) Crew time to conduct experiments
d) Facilities to house, observe, and manipulate small mammals

3. What is the greatest advantage to using the ISS for your research? What benefits do you get from using the ISS that you cannot get from a ground-based research facility?

The greatest advantage is long-term access to a laboratory that resides in a continuous free-fall environment ("microgravity"). It is not available anywhere else.

4. What is the greatest obstacle for you in getting your research to the ISS? Do NASA and CASIS have a positive reputation in the microgravity research community or are there things that can be improved upon?

The missions of NASA and CASIS, as currently defined, are fundamentally different. NASA enables exploration, with a destination/goal of Mars. CASIS provides access to the National Laboratory component of the International Space Station. However, the National Laboratory has no particular obligation to fulfill an exploration mission. While CASIS-sponsored research may have scientific or commercial merit, its research portfolio will not necessarily contribute to human exploration of Mars unless the National Laboratory, and therefore CASIS, is specifically directed to do so.

5. **In your written testimony, you state that the ISS is lacking critical components for research that would be important for learning how human physiology would respond in fraction (*sic*) gravity environments. Can you tell the Committee what NASA should be doing to invest more in this area and what needs to be done on the ISS to find answers to this question?**

Two essential research capabilities are needed to address this issue: First, a centrifuge facility capable of rotating mammals at velocities sufficient to induce centrifugal forces that span the range of 0-1 G loading. Second, an ability to study mammalian adaptation to this environment for periods of time approximating exploration-class missions (i.e., one year or longer).

It is tempting to assume that the biological response in the fractional environment is linear; in other words, that 38% of the earth's gravitational loading will elicit 38% of a biological response. However, this hypothesis has not been tested rigorously. By varying the centrifugal force in free fall, the biological response to these fractional loads can be determined. By establishing a body evidence at specific points in the gravitation continuum (e.g., lunar gravity, Martian gravity), we may be able to interpolate responses at other points between.

NASA has developed a comprehensive countermeasures program to mitigate some of the cardiovascular, neurovestibular, muscular, and bone adaptions to spaceflight. Neither the long term efficacy of these programs nor the asymptote at which biological systems assume a new steady-state has been fully established. To better inform these gaps, more samples are necessary over longer periods of time. Thus, program extension plays a critical role in risk reduction.

Thank you for the opportunity to address the Subcommittee. Please feel free to contact me should you have further questions or comments.

Sincerely,

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September 10, 2015

The Honorable Donna Edwards
Ranking Member, Subcommittee on Space
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Congress of the United States
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Dear Ms. Edwards:

Thank you for the opportunity to respond to your follow up questions from the hearing "The International Space Station: Addressing Operational Challenges" held on July 10, 2015. Written responses to your questions are provided below. These are my personal opinions and do not necessarily represent those of my employer or the advisory groups with whom I consult.

1. **How does CASIS's process for reviewing and evaluating the research they select and manage differ, if at all, from that of the scientific community? What issues do such differences raise for the conduct of research on the ISS?**

I am not a regular user of the CASIS mechanism so I cannot offer well-informed comment on CASIS's criteria for science selection and management. The missions of NASA and CASIS, as currently defined, are fundamentally different. NASA enables exploration, with a destination/goal of Mars. CASIS provides access to the National Laboratory component of the International Space Station. However, the National Laboratory has no particular obligation to fulfill an exploration mission.

CASIS appears to be developing "grand challenge" strategies that are scientifically interesting. For example, the current solicitation for "3D Microphysiological Systems for Organs-On-Chips Research" is a notable example of an outstanding research idea whose need for ISS access is not obvious. Whereas such CASIS-sponsored research may have important scientific or commercial merit, CASIS's efforts will not necessarily contribute to human exploration of Mars unless the National Laboratory, and therefore CASIS, is specifically directed to do so.

2. **In your prepared statement, you state that "Unless we improve our research centrifuge capabilities on the !SS, we accept a risk of sending humans to Mars with little or no knowledge of how mammalian biology responds in a gravitational field other than Earth's." Could you elaborate on your concern? What type of centrifuge could the ISS**

reasonably accommodate and could it enable the research that you indicate is needed to help inform a future human mission to Mars? If not, what is needed?

At a minimum, I believe it is desirable to implement a centrifuge facility capable of rotating small mammals at velocities sufficient to induce centrifugal forces that span the range of 0-1 G.

It is tempting to assume that the biological response in the fractional environment is linear; in other words, that 38% of the earth's gravitational loading will elicit 38% of a biological response. However, this hypothesis has not been tested rigorously. By varying the centrifugal force in free fall, the biological response to these fractional loads can be determined. After establishing a body evidence at specific points in the gravitation continuum (e.g., lunar gravity, Martian gravity), we may be able to interpolate responses at other points between. Perhaps there is a threshold level (either magnitude or duration) of loading that will arrest biological changes in space that have a negative impact on exploration (e.g. loss of muscle and bone mass). The putative threshold is not known.

3. **There are two U.S. entities with access to facilities and crew time on the ISS-NASA and CASIS. Given the constraints on available crew time for research, to what extent are NASA and CASIS coordinating and collaborating on research and what are the mechanisms for collaboration? Are any changes needed?**

From a research perspective, there are many reasons to have, maintain, and extend the International Space Station. In no particular order, I identify the following:

a. Discovery science that advances basic understanding. The goal of such research is new knowledge rather than knowledge application.
b. Translational science that enables human exploration beyond low-earth orbit. Based on the anticipated state of spacecraft and propulsion design, one can reasonably expect that such missions will exceed a year in duration and will immerse astronauts in a higher energy radiation environment than they encounter in low-earth orbit. Such challenges define a research program whose outcome is knowledge and technology products that enable exploration.
c. Translational science that develops or increases commercial opportunities on earth. Products from this type of research generate a return on investment that is quantifiable in monetary terms. They may or may not support exploration or discovery goals.

A note of caution is in order: fundamental or "discovery" science has lowest priority within NASA today, with allocations of research time that are alarmingly low. In my opinion, Congress would be wise to provide direction on the allocation of time between National Laboratory and NASA sponsored research; perhaps focusing National Laboratory research on either discovery science (freeing NASA time allocations for more exploration focused research) or vice-versa. Either direction will require more coordinated efforts between National Laboratory activities and NASA-sponsored activities on the ISS. Emphasizing "return on investment" metrics with short time horizons (< three years) is unlikely to result in a research portfolio that enables either discovery science or long-duration human exploration of space.

In plain language, NASA needs a stronger voice in the direction and implementation of National Laboratory activities.

4. How important is downmass capability for the conduct of research on the ISS? How will the current unavailability of the Dragon, which has pressurized downmass to return biological samples, affect the research that can be carried out on the ISS at this time?

Because I do not work with the Dragon system, I am unable to provide a thorough answer to the Subcommittee on this question. In general, rack-mounted experiments are relatively platform independent.

5. In a NASA report titled "International Space Station (ISS) Sustainability Plan" that was transmitted to Congress pursuant to language in the explanatory statement accompanying the FY 2014 Onmibus (*sic*) Appropriations Act, NASA stated that "Research on the !SS is necessary to mitigate 21 of the 32 human health risks anticipated on long-duration exploration missions. The flight resources available to study and mitigate these risks are insufficient prior to 2020 ... operating the ISS through at least 2024 will help to mitigate these risks." How much progress is being made on mitigating the identified human health risks for long-duration exploration missions? Will NASA have sufficient research results to mitigate all of the identified human health risks, should the ISS be extended to 2024? If not, what should be done?

My testimony is based, in part, on review of the ISS Sustainability Plan. As you note, NASA reports that some risks will not be completely mitigated, even at the conclusion of the extension period. This is not necessarily a reflection of research program adequacy as much as it is a reflection of unclear programmatic goals. In other words, a program that needs to provide for any possible exploration scenario cannot possibly mitigate all conceivable risks. More thorough task analysis of proposed mission designs should help keep the research program focused on long-term exploration goals.

Simply stated, at the conclusion of the ISS program we should expect, from a biological perspective, to know enough to successfully send and return humans to the Martian surface (or any other mission of similar duration). Because no follow on activities are planned that would address the risks of exploration-class missions, there can no more important goal for having a long duration research platform in low-earth orbit.

6. In your prepared statement you say that it is of paramount importance "That NASA's research management structure be optimized to meet its discovery, translational research, and commercialization goals. The utility of a coherent research plan that is appropriately resourced and consistently applied to enable exploration cannot be overemphasized." Do you have any thoughts on how NASA's research management structure could be optimized? Could you provide more detail as to what you mean by a "coherent research plan"?

In my opinion, the greatest impediment to meeting the three aforementioned goals is the arbitrary allocation of research resources between the National Laboratory and NASA-sponsored research. The 50-50 allocation of crew time between the two entities constrains government-sponsored research. If the translational research needed for Mars is not completed before the conclusion of the ISS program then the risk posed to humans during long-term exploration will increase.

Our government has a history of funding discovery research when the immediate impact to society is uncertain. Such research languishes when return on investment becomes a prominent consideration for research allocation. NASA deserves high praise for regenerating a discovery research portfolio in the biological and physical sciences. However, discovery research in the biological and physical sciences is not an overt expectation of the ISS National Laboratory; in fact, CASIS's stronger emphasis on a commercial business model encourages quite the opposite.

Parenthetically, the economic value of a commercial research platform can be quantified by the investments that the commercial sector is willing to make. The value of CASIS would be known unambiguously if research resources (time, volume, power) were auctioned, similar to the FCC's auctions of the electromagnetic spectrum.

A "coherent research plan" would do more than recognize the three research goals mentioned earlier (discovery, translation, and commercialization); it would prioritize and weight them and allocate resources accordingly. Once these rankings are determined, possible implementation strategies are provided in the LMS Decadal Study. However, today such planning is constrained by the National Laboratory authorization language and the equal allocation of ISS research resources that resulted.

The National Laboratory component of the ISS has neither the charge nor the expectation to enable our government's long-term investment in exploration. Alternate models should, at a minimum, provide NASA a stronger voice in the selection and implementation of CASIS-sponsored research, and authorize NASA to revisit the 50-50 resource allocation model under which it operates the National Laboratory today.

Thank you for the opportunity to address the Subcommittee. Please feel free to contact me should you have further questions or comments.

Sincerely,

Jim Pawelczyk, Ph.D.
Associate Professor of Physiology, Kinesiology and Medicine

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